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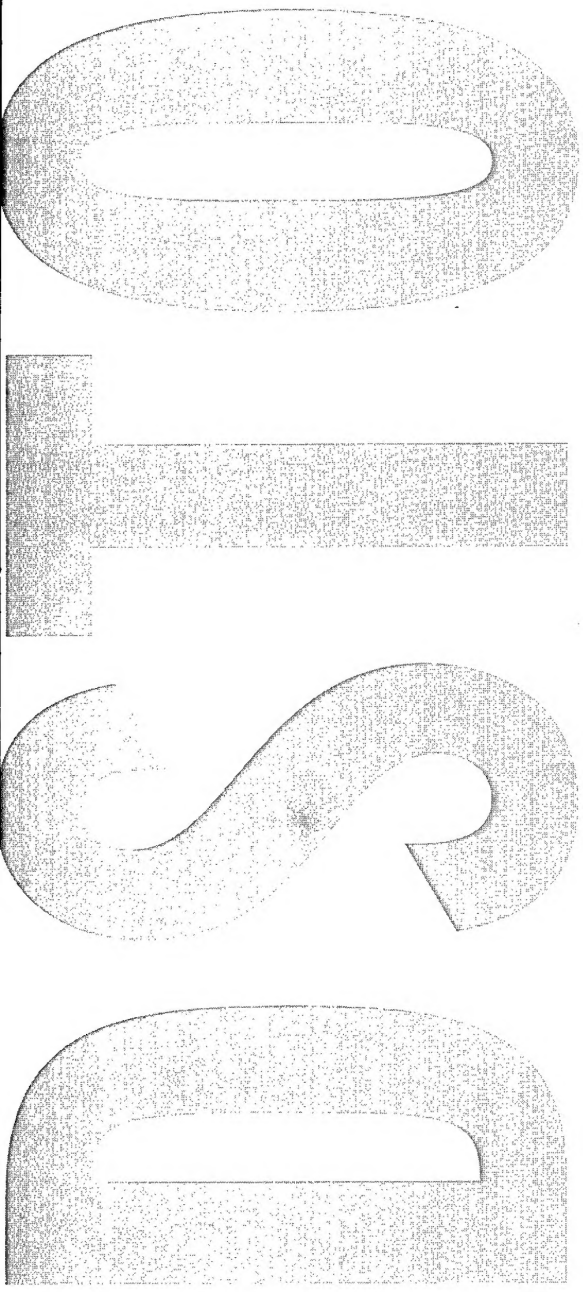

Calibration of the Reference Velocity in the Test Section of the Low Speed Wind Tunnel at the Aeronautical and Maritime Research Laboratory

Craig D. Edwards

DSTO-TN-0248

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ABSTRACT

The measurement of wind velocity in the test section of the Low Speed Wind Tunnel is obtained from the measurement of dynamic pressure using two piezometer rings located at the entrance and exit of the tunnel contraction. Following the recent installation of a new contraction, a calibration of the dynamic pressure measurement system was performed to determine a new wind tunnel 'calibration' factor. This factor is applied as a correction to the pressure measurements obtained from the two piezometer rings to represent accurately the correct dynamic pressure and consequently, velocity, at the centre of the test section midway between the centres of the turntables in the floor and ceiling. A sub-standard pitot-static probe was used to acquire pressure data at various positions within the wind tunnel test section for a range of velocities. The new tunnel calibration factor, representative of all wind speeds, was determined to be 1.079, an increase of 3.3% over the factor of 1.045 for the previous contraction. This report contains all of the test data and a detailed account of the procedure and equipment used to derive this new calibration factor.

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Calibration of the Reference Velocity in the Test Section of the Low Speed Wind Tunnel at the Aeronautical and Maritime Research Laboratory

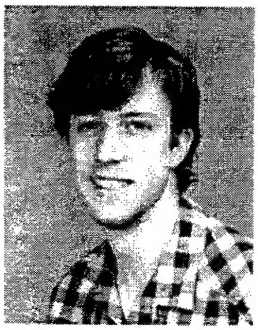
Executive Summary

The measurement of velocity in the Low Speed Wind Tunnel (LSWT) at the Aeronautical and Maritime Research Laboratory (AMRL) is obtained from two piezometer rings located at the entrance and at the exit of the tunnel contraction. The recent installation of a new contraction has made it necessary to perform a calibration of this system in order to measure accurately the dynamic pressure, or the velocity, in the wind tunnel test section. From this calibration, a wind tunnel 'calibration' factor has been determined which must be applied to the piezometer ring pressure measurements to obtain a dynamic pressure representative of the flow at the centre of the test section midway between the centre of the turntables in the floor and ceiling. This report details the experimental equipment and process used to determine this factor and it contains all of the results obtained.

The true dynamic pressures at various locations in the wind tunnel test section were measured using a NPL sub-standard pitot-static probe. Relationships between this data and the piezometer ring measurements were analysed to enable a new wind tunnel calibration factor to be calculated. A value of 1.079 was determined which corresponded to a 3.3% increase over the factor of 1.045 for the previous contraction. This relatively large increase was attributed to the effects of the installation of the new shorter contraction which consequently led to a longer test section. The longer test section caused an increase in boundary layer thickness and consequently a greater velocity in the test section where a model would normally be mounted.

It is recommended that similar wind tunnel calibrations be performed every two to three years to ensure accurate velocity measurements are provided for items being tested.

Authors



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Craig graduated from the University of Queensland in 1995 completing a Bachelor of Mechanical and Space Engineering with First Class Honours. The following year he obtained employment with the Aeronautical and Maritime Research Laboratory in Melbourne. Working in Flight Mechanics, he has gained considerable experience in the area of wind tunnels and experimental aerodynamics including test programmes with the Hydrographic Ship and PC-9/A aircraft. He has also been involved extensively in the development of wind tunnel data acquisition systems.

Contents

Notation

A_A	Cross sectional area of tunnel upstream of the contraction at the location of piezometer ring 1
A_B	Cross sectional area of tunnel downstream of the contraction at the location of piezometer ring 2
A_C	Cross sectional area of the tunnel test section at the centre of the turntables
H	Local total pressure from pitot-static probe
K	Test section calibration factor
K_1	Pressure loss coefficient for contraction
L	Characteristic length
P	Local static pressure from pitot-static probe
P_A	Static pressure at piezometer ring 1 upstream of the contraction
P_B	Static pressure at piezometer ring 2 downstream of the contraction
ΔP_{piezo}	Pressure difference across piezometer rings = $P_A - P_B$
ΔP_{pitot}	Dynamic pressure from pitot-static probe = (H–P)
q	Dynamic pressure
R	Gas Constant for Air = 287 $Jkg^{-1}K^{-1}$
Re	Reynolds Number
V_A	Velocity in tunnel upstream of the contraction at piezometer ring 1
V_B	Velocity in tunnel downstream of the contraction at piezometer ring 2
V_C	Velocity in test section at the centre of the turntables
T_o	Total temperature
X,Y,Z	Axes system as defined in Figure 4.
ρ	Air density

Units

kg	kilogram
kPa	kilo Pascal
m	metre
mmH_2O	millimetres of water
Pa	Pascal
psid	pounds per square inch differential
s	second

1. Introduction

The wind velocity in the test section of the Low Speed Wind Tunnel (LSWT) at the Aeronautical and Maritime Research Laboratory (AMRL) is obtained from pressure measurements using two piezometer rings located at the entrance and exit of the tunnel contraction. Pressure losses associated with tunnel geometry, flow irregularities and boundary layer growth mean that the pressure difference measured by the piezometer rings does not accurately represent the true dynamic pressure within the tunnel test section. To correct for these losses, a 'tunnel calibration factor' is required to determine the velocity in the test section.

Considerable time has passed since the previous evaluation of this factor and little documentation exists on its establishment. Static pressure and velocity distributions in the wind tunnel test section have been investigated previously (*Matheson*, 1983) mainly with the objective of determining the static pressure gradient in the test section so that buoyancy corrections could be made on long models. The recent installation of a new contraction has made it necessary to perform tests to determine a new calibration factor. This report describes the tests used to obtain the new calibration factor.

Pressure data was acquired from an NPL sub-standard pitot-static probe at various positions within the tunnel test section over a large velocity range. These measurements were then compared with those obtained from the piezometer rings. This report contains the experimental results in tabular and graphical format. Graphs have been created which display the variation of the wind tunnel calibration factor at a range of positions in the test section. These were then used to determine an 'average' calibration factor for the flow at the centre of the tunnel cross section midway between the centre of the turntables where a model would normally be mounted.

2. Wind Tunnel and Equipment

2.1 Low Speed Wind Tunnel Description

The AMRL Low Speed Wind Tunnel is a closed circuit continuous flow tunnel with a contraction ratio of 4:1, capable of producing wind velocities of up to 100 ms^{-1}. The test section is an irregular octagonal shape with a height of 2.13 m and a width of 2.74 m. The method of velocity measurement is via piezometer rings located before and after the tunnel contraction. An outline of the plan of the wind tunnel is shown in Figure 1.

A new tunnel contraction shape, based on the design by Watmuff (*Watmuff, 1986*), was recently constructed in the tunnel to extend the working section and improve flow quality (*Erm*). The new contraction made it necessary to relocate the upstream piezometer ring further upstream. Consequently, a new tunnel calibration was required.

The static pressure drop between the two piezometer rings, A and B, provides an estimation of the dynamic pressure and consequently velocity, within the test section (*Gorlin et al, 1966 and Rae et al, 1984*). Referring to Figure 2, and applying the energy equation between these two stations gives:

$$P_A + \frac{1}{2}\rho V_A^2 = P_B + \frac{1}{2}\rho V_B^2 + K_1 \frac{1}{2}\rho V_B^2 \qquad (1)$$

where P is the static pressure and V is the velocity;

K_1 is the coefficient for pressure losses associated with the tunnel contraction geometry and other flow irregularities, between the piezometer rings at stations A and B;

Subscript A denotes the station for the piezometer ring upstream of the contraction;

Subscript B denotes the station for the piezometer ring downstream of the contraction.

With the continuity equation for incompressible flow,

$$A_A V_A = A_B V_B = A_C V_C \qquad (2)$$

where subscript C denotes a cross section in the test section, then equation (1) reduces to

$$P_A - P_B = \frac{1}{2}\rho V_C^2 \left[\left(\frac{A_C}{A_B} \right)^2 (1 + K_1) - \left(\frac{A_C}{A_A} \right)^2 \right] \qquad (3)$$

or

$$\begin{aligned} \frac{1}{2}\rho V_C^2 &= K(P_A - P_B) \\ &= K(\Delta P_{piezo}) \end{aligned} \qquad (4)$$

where K is the tunnel calibration factor and is determined using the method described in Section 3.

2.2 Experimental Equipment

The manner in which the experimental equipment was connected is shown in the schematic drawing in Figure 3. The low pressure tubes from the piezometer rings and pitot-static probe were connected to a switch (SW 1) and similarly the high pressure tubes were connected to another switch (SW 2). By operating both switches together, the pressure source required can be selected. The outputs of each switch were then connected to two pressure measuring devices, a Betz Manometer and a 15 psid Digiquartz, as described below.

2.2.1 Pitot-Static Probe

Dynamic pressure measurements within the wind tunnel test section were measured using an NPL sub-standard pitot-static probe. The probe was placed at 15 different locations within the tunnel as shown in Figure 4. Probe positions were measured according to conventional wind tunnel axes (*Fairlie, 1985*) with the origin (x = y = z = 0) defined as the point along the tunnel centreline midway between the centres of the turntables.

The pitot probe was mounted in the test section using the slots in the turntable. The test points were selected to obtain a reasonable cover of the volume in which a model would normally be tested using the existing slots in the turntables. For positions above and below the plane z = 0, the probe was simply mounted through the slots in the upper and lower turntables respectively. The appropriate turntable was rotated and the probe direction adjusted so that it was effectively in line with the flow for each test. Two guide wires (piano wire) were attached at the approximate midpoint of the probe shaft for test points along the z = 0 plane. These wires strengthened the rig and prevented excessive deflection of the pitot-static probe during higher wind velocities.

2.2.2 Digiquartz

The pressures from both the piezometer rings and the pitot-static tube were measured using the 15 psid Digiquartz, serial number 12555 and a Paroscientific Pressure Computer Model 700. The Digiquartz transducer was calibrated on the 13th November, 1996 and the calibration constants determined were entered into the pressure computer. From the calibration, the average error in the pressure measurements using the Digiquartz was 0.012% of the applied pressure, which corresponds to 12 Pa at full scale. This equipment enabled the actual pressures to be displayed in real time during the experiment.

2.2.3 Betz Manometer

In addition to the Digiquartz, a Betz Manometer, serial number ARL639 was also used to determine pressures. This was used to verify the recorded data and to provide a comparison of the accuracy between the two instruments. Two corrections to the Betz Manometer pressures were made. First, the physical scale of the Betz manometer reads up to 400 mm of H_2O but a device was fitted to the instrument to increase its range to 800 mm of H_2O. Therefore the readings (on the 400 mm H_2O scale) were multiplied by a factor of two to obtain the true readings. Second, the Betz Manometer had been recently calibrated using a Dead Weight Tester, and this had shown that there was a linear relationship between the measured and actual pressures (Figure 5). The linear equation determined from the calibration including the ×2 correction is given in equation 5 and it was used to obtain the actual pressures.

$$P_{actual} = \frac{2P_{measured} - 0.154}{0.9922} \qquad (5)$$

This correction is automatically performed in the computer software that records the data, as indicated in Section 2.3.

2.3 Computer Software for Data Recording

A simple computer program called *'wtcal'* was developed to log the freestream parameters and prompt the user for input of the pressure measurements obtained from the Betz manometer (mmH2O) and Digiquartz (Pa). This software is located in the *[lswt.wtcal]* directory on the LSWT MicroVAX II data acquisition system. When running the program, the operator is first prompted for a filename to which the data from a particular test run will be saved. If the file exists, the user has the option of appending the data to the old file, overwriting the old file or changing the filename.

When a 'G' is typed at the command prompt, the data acquired by the LSWT freestream parameters instrumentation module will be recorded. The user is then required to enter via the keyboard the pressure measurements obtained from the Digiquartz and Betz Manometer for both the piezometer rings and pitot-static probe. This process continues until an 'E' is typed which ends the program. The command 'R' enables the user to reject the last line of data at any point during the test.

Two files are created during this procedure, a *'.DAT'* file and a *'.OUT'* file. The file with extension *'.DAT'* contains all of the raw data as recorded by the data acquisition system and entered from the keyboard. The *'.OUT'* file, contains a preliminary analysis of the pressure data. This includes the calculation of corresponding velocities and the wind tunnel calibration factors, K, at the completion of every test point.

3. Test Procedure and Test Results

Tests were performed at each of the 15 probe positions identified in Figure 4, with wind speeds ranging from 5 ms^{-1} to 90 ms^{-1}. At each 5 ms^{-1} wind speed interval, the differential pressure from the piezometer rings was recorded via the Betz Manometer and the Digiquartz. The switches were then reversed and the dynamic pressure from the pitot-static probe was measured on both instruments in an identical manner. These four readings for each wind speed were registered on a data sheet and entered into the computer program *'wtcal'* as described in Section 2.3. The wind tunnel speed was kept as constant as possible during the measurement of all four pressures to obtain an accurate calibration.

The data containing the freestream parameters and the measured pressures for the entire test program is presented in Appendix A.

3.1 Error in Reading Pressure Measurements

Some difficulty was encountered in reading the pressures from the Betz manometer and Digiquartz due to pressure fluctuations and instrument resolution. Intermittently during the test program at various wind speeds, a range of pressures were recorded to provide an indication of the error in reading the instruments. Table 1 shows the reading accuracy of the Betz Manometer compared with that of the Digiquartz. There were no significant differences in reading accuracy between the two instruments.

Table 1. Error in Reading Pressure Measurements

Nominal Velocity (ms^{-1})	Pressure Reading		Error in Pressure		% Error in Pressure	
	Betz (mmH_20)	Digiquartz (Pa)	Betz (mmH_20)	Digiquartz (Pa)	Betz	Digiquartz
5.0	1.0	17.5	±0.1	±1.5	±10.0	±8.57
20.0	13.4	261.5	±0.1	±2.0	±0.75	±0.76
40.0	52.7	1038.7	±0.2	±3.0	±0.38	±0.29
60.0	116.7	2297.0	±0.2	±3.0	±0.17	±0.13
80.0	214.8	4239.0	±0.2	±5.0	±0.09	±0.12

NOTE: The Betz Manometer pressure readings in this table have not been corrected according to the instrument's range and calibration characteristics and therefore are approximately half the magnitude of the measurements from the Digiquartz. They need to be multiplied by two (see Section 2.2.3) to enable the results to be directly comparable.

3.2 Data Reduction and Wind Tunnel Calibration Factor Calculation

Linear regressions were performed on the pressure data obtained from the piezometer rings and pitot-static tube for each probe position to obtain a calibration factor, K. The equation used was:

$$(H - P) = \Delta P_{pitot} = K\Delta P_{piezo}$$

where ΔP_{pitot} = the differential pressure measured by the pitot-static probe (Pa)
ΔP_{piezo} = the measured differential pressure from the piezometer rings (Pa)
K = the line gradient = the wind tunnel calibration factor for each test point

From this relationship, a wind tunnel factor was determined for each individual probe position within the wind tunnel test section. Figure 6 to Figure 20 show the test results and the linear equation that was calculated for each probe position. The data obtained from both the Digiquartz and the Betz Manometer are displayed on each graph.

The wind tunnel factors determined from the linear regression analyses are summarised in Table 2. The calibration factor was plotted across the X-Z and Y-Z planes within the tunnel test section and these graphs are shown in Figure 21 and Figure 22.

Table 2. Wind Tunnel Factors at each probe position in the test section

Probe Position	x (mm)	y (mm)	z (mm)	Wind Tunnel Calibration Factors (K)	
				Betz Manometer	Digiquartz
1	830	0	-535	1.088	1.087
2	830	0	0	1.073	1.072
3	830	0	535	1.088	1.087
4	0	0	-535	1.095	1.094
5	0	0	0	1.082	1.082
6	0	0	535	1.094	1.094
7	-530	0	-535	1.098	1.097
8	-530	0	0	1.084	1.084
9	-530	0	535	1.097	1.096
10	0	-657	-535	1.088	1.086
11	0	-657	0	1.095	1.094
12	0	-657	535	1.105	1.104
13	0	657	-535	1.086	1.086
14	0	657	0	1.097	1.096
15	0	657	535	1.079	1.078

From this data, it was necessary to determine a single wind tunnel calibration factor that was representative of the flow conditions in the centre of the test section at station C in Figure 2.

Since the differences in dynamic pressure throughout the test section were not large, a weighted average of the measurements was considered unnecessary.

There is no significant difference between the calibration factors obtained from the Betz manometer and the calibration factors obtained from the Digiquartz. As the Digiquartz is considered to have a greater accuracy and is widely accepted, only Digiquartz measurements were used in the analysis.

Since most wind tunnel models are usually mounted along the centreline of the tunnel, it was decided that the tunnel calibration factor would be calculated from the average of the Digiquartz measurements along the x-axis centreline (i.e., positions 2, 5 and 8).

Consequently, the new value of the tunnel calibration factor K, is

$$\mathbf{K = 1.079}$$

A calibration factor of K = 1.089 results if all 15 positions are used in the analysis.

3.3 Discussion

The new calibration factor of 1.079 for the wind tunnel is approximately 3.3% greater than the previous factor of 1.045. The installation of the new contraction is an obvious reason for

this increase. Apart from improving the uniformity of the flow in the test section, the primary benefit of the new contraction was to increase the length of the test section. This length has been increased from 4.11 m to 6.55 m. The test section now extends much further forward of the centre of the turntables, so that the boundary layer on the tunnel walls will be approximately 26% thicker and this is expected to cause most of the increase in the calibration factor.

Using the calibrated accuracy of the Digiquartz and the reading accuracy of the Digiquartz, approximate errors in the wind tunnel factor have been determined. At 20 ms^{-1}, the wind tunnel factor accuracy is estimated to be 1.079 ± 0.017. At 40 ms^{-1}, the accuracy is approximately 1.079 ± 0.003. At 60 ms^{-1} and 90 ms^{-1}, the accuracy is approximately 1.079 ± 0.003.

4. Conclusions

The piezometer rings in the Low Speed Wind Tunnel are used to provide a measure of dynamic pressure in the test section. These piezometer rings were calibrated against a NPL sub-standard pitot-static probe that was used to measure the local dynamic pressure at various locations of the test section. This enabled a new wind tunnel calibration factor of 1.079 to be determined for the Low Speed Wind Tunnel. This factor is applied as a correction to the pressure difference measured by the piezometer rings, so that a representative dynamic pressure, and velocity, is obtained at the location of a model midway between the centre of the turntables in the test section.

The wind tunnel calibration factor has increased to 1.079 from the previous factor of 1.045. This increase was attributed primarily to the installation of a new contraction and longer test section, which produced a thicker boundary layer on the test section walls and increased the air velocity where a model would normally be positioned.

All data is contained in this report to allow further appropriate analysis and comparison if required. Details of the method and equipment have been included as a basis for any future calibrations. It is recommended that similar wind tunnel calibrations be performed every two to three years, or after any modification in the contraction/test section region of the wind tunnel, to ensure accurate velocity measurement.

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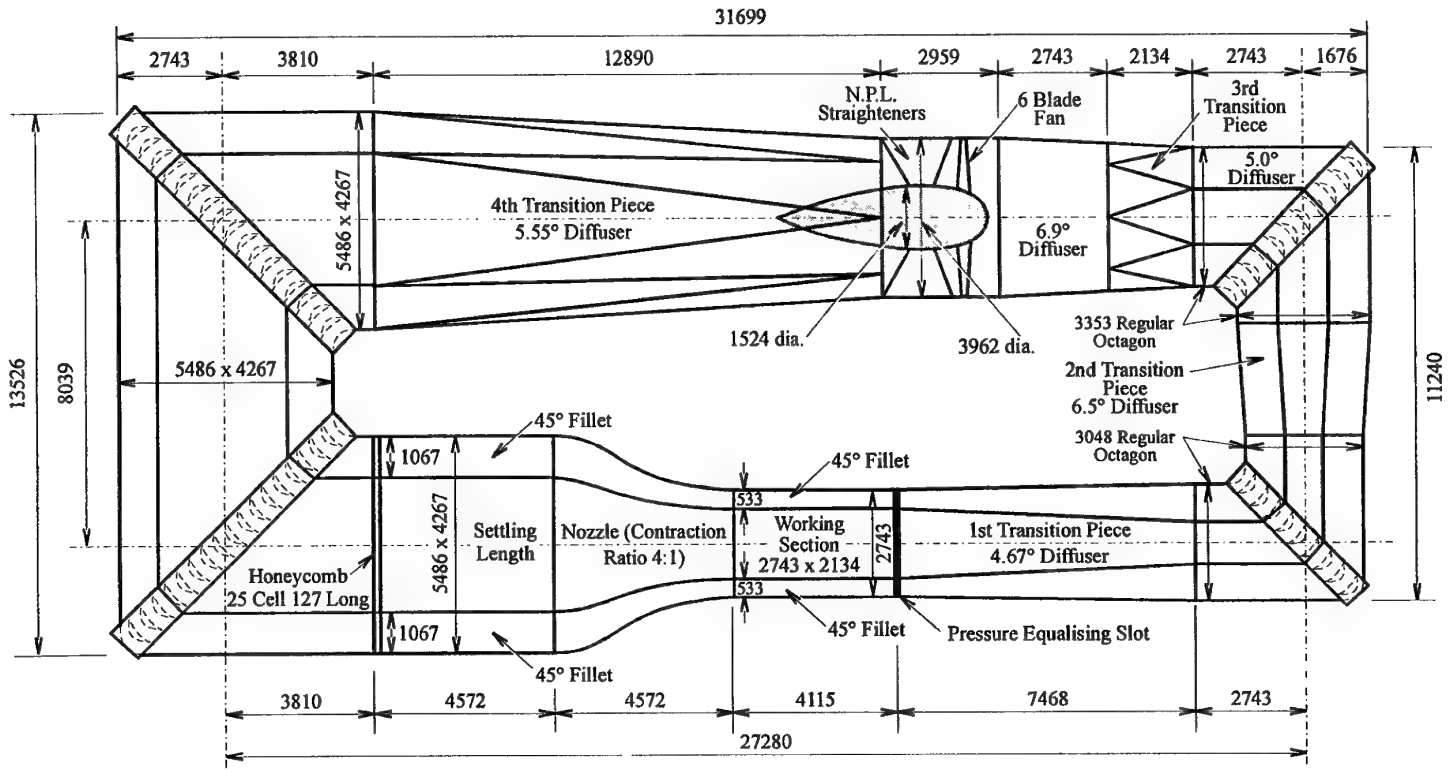


AERODYNAMIC OUTLINE - AMRL 2.7 m x 2.1 m WIND TUNNEL

ASTA Defence Drawing Office - File Name: 9x7_met.cdr - RFQ D04424 - Revision Date: 21 March 1997

All dimensions in mm

Figure 1. Aerodynamic Outline of the AMRL 2.74 m × 2.13 m Low Speed Wind Tunnel

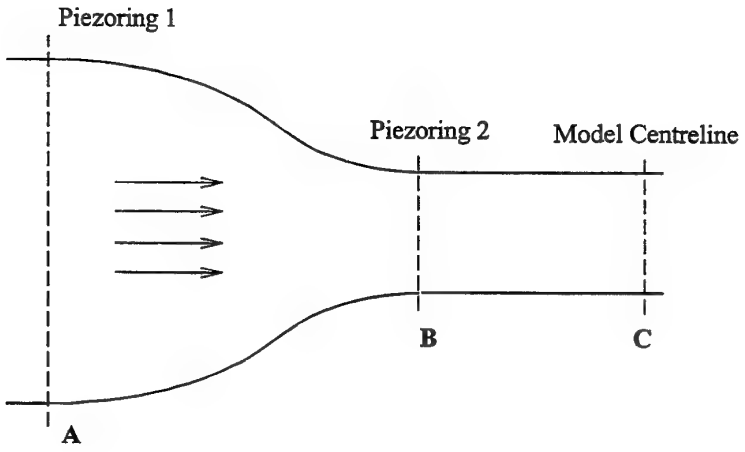


Figure 2. Determination of velocity from the static pressure drop between piezometer rings

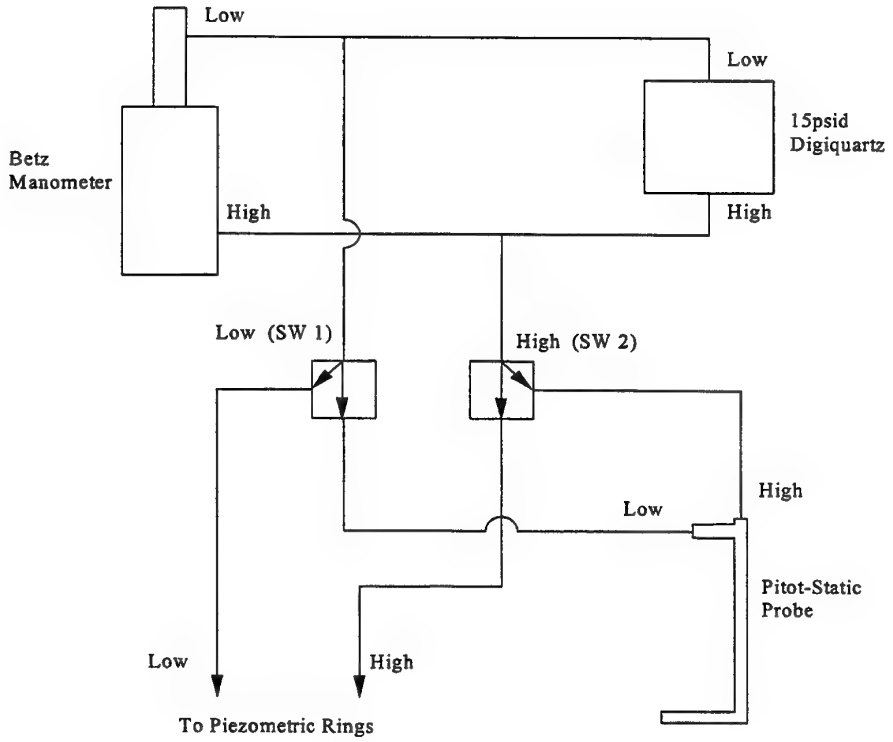
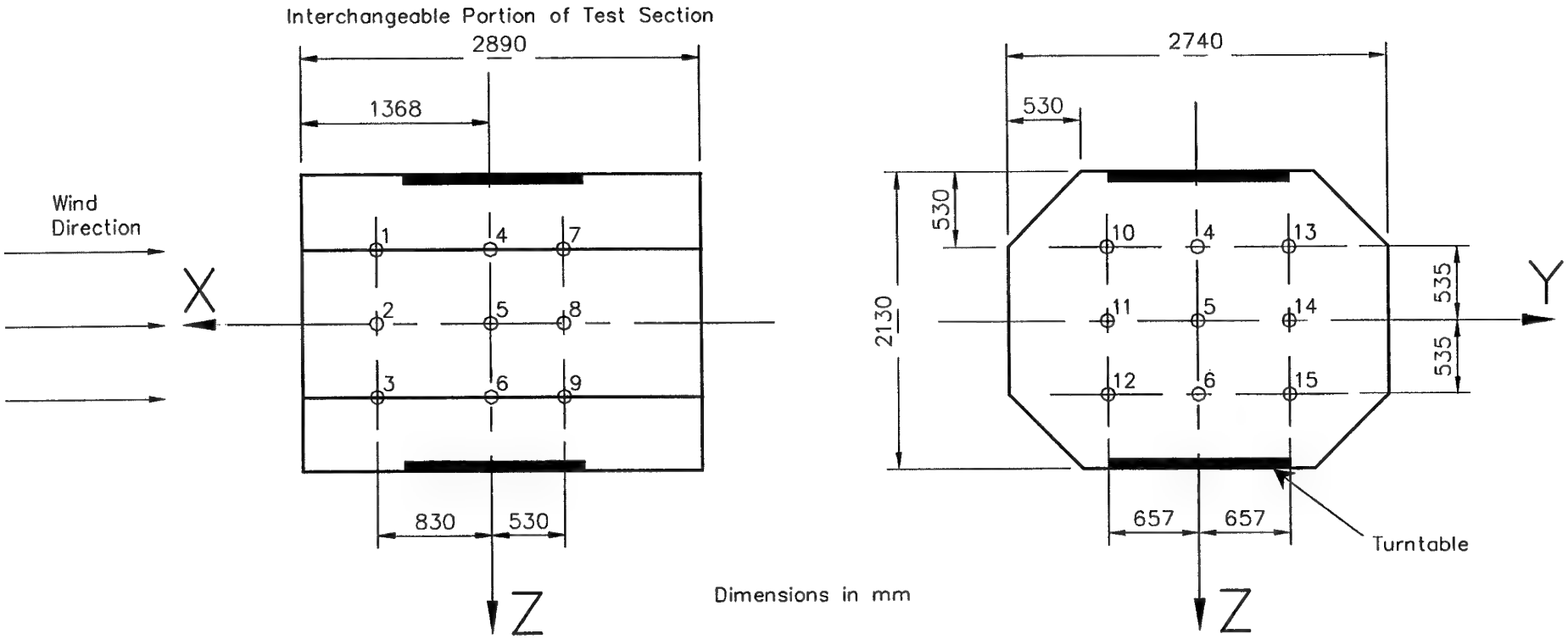


Figure 3. Schematic of the experimental set-up



(a) Side view of the test section

(b) Cross section of the test section at the centre of the turntables

Figure 4. Schematic of the tunnel test section and pitot-static probe positions 1-15

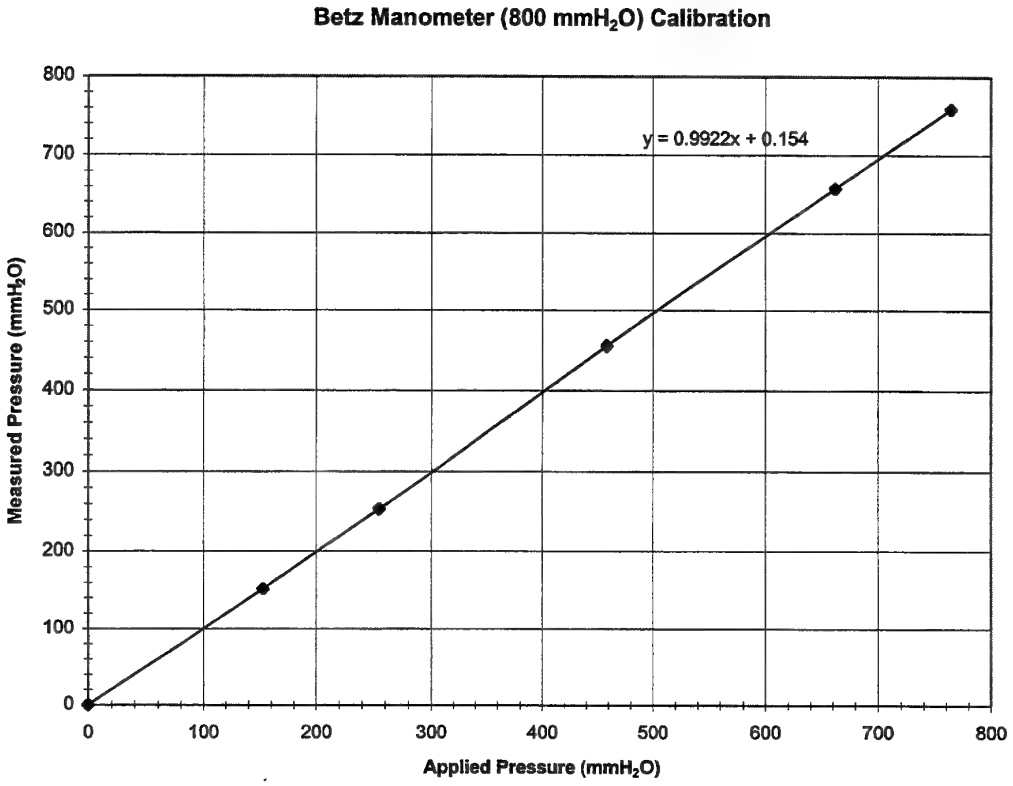


Figure 5. Betz Manometer Calibration 28th October, 1996

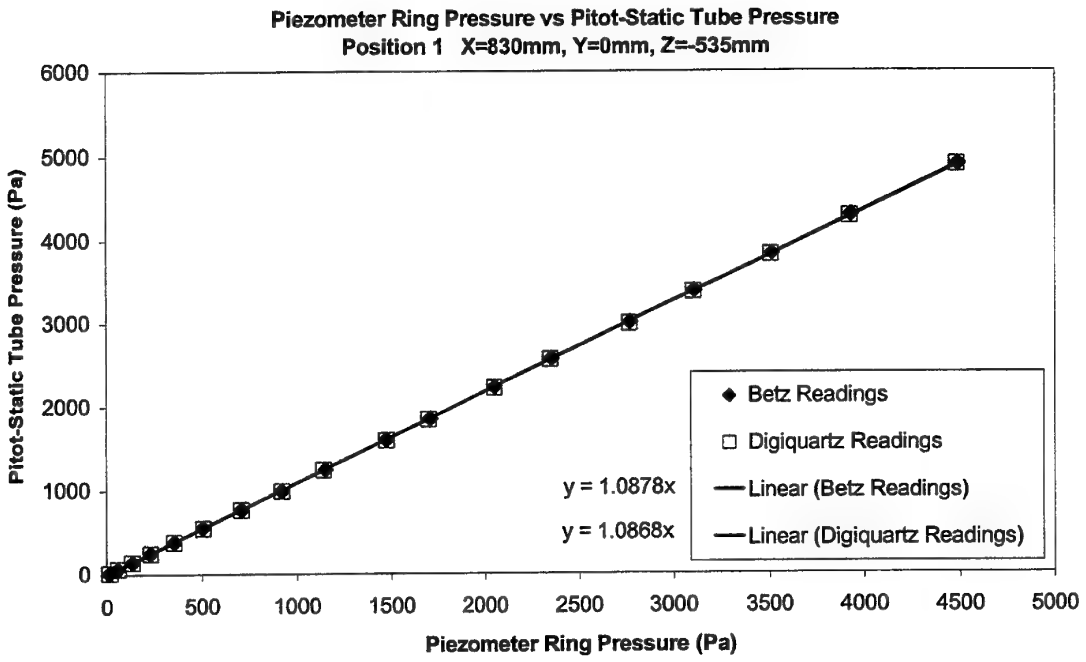


Figure 6. Linear regression of piezometer ring and pitot-static tube pressures - Position 1

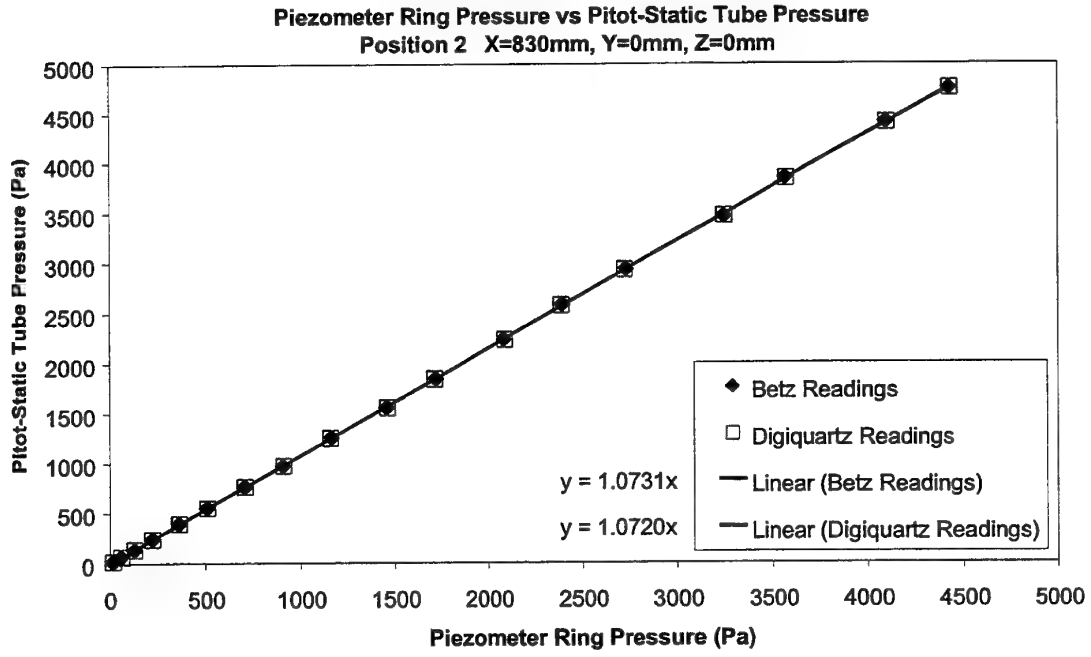


Figure 7. Linear regression of piezometer ring and pitot-static tube pressures - Position 2

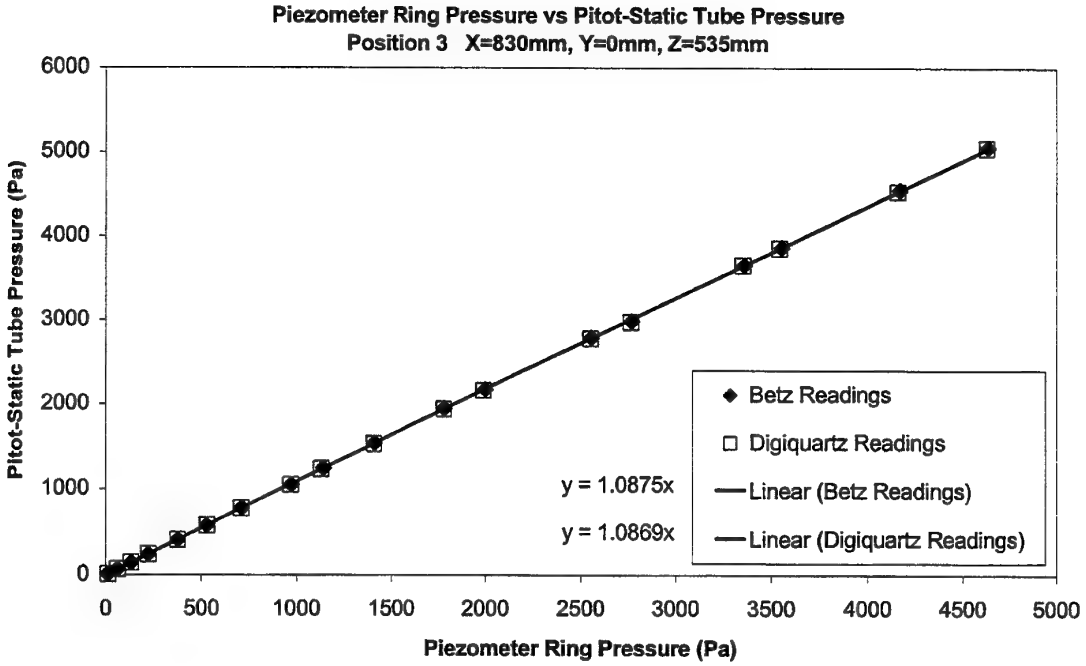


Figure 8. Linear regression of piezometer ring and pitot-static tube pressures - Position 3

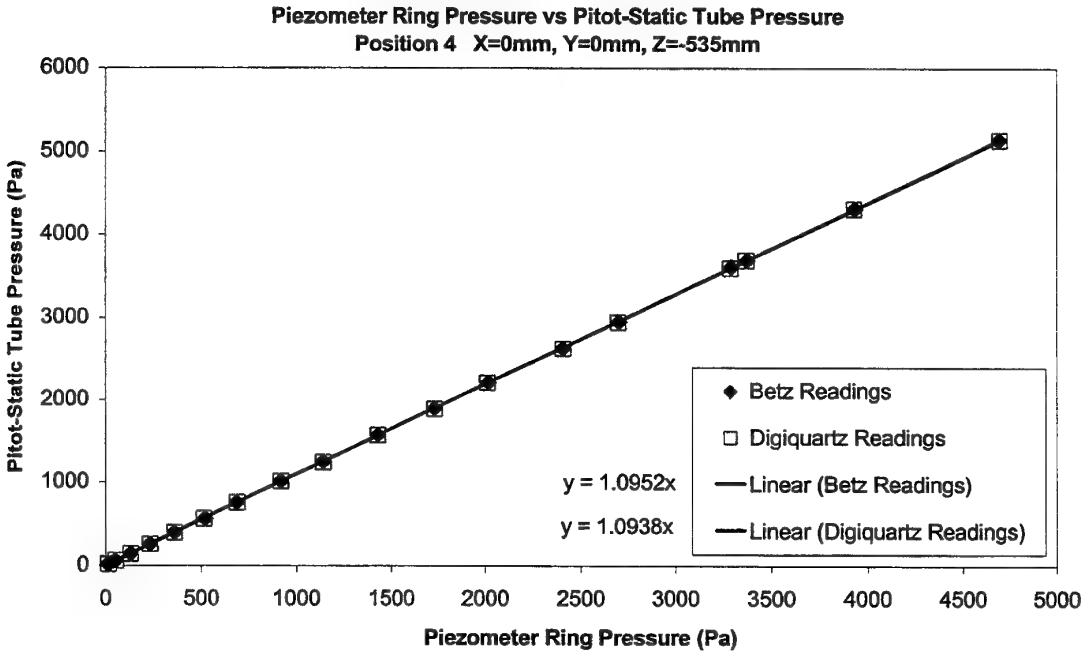


Figure 9. Linear regression of piezometer ring and pitot-static tube pressures - Position 4

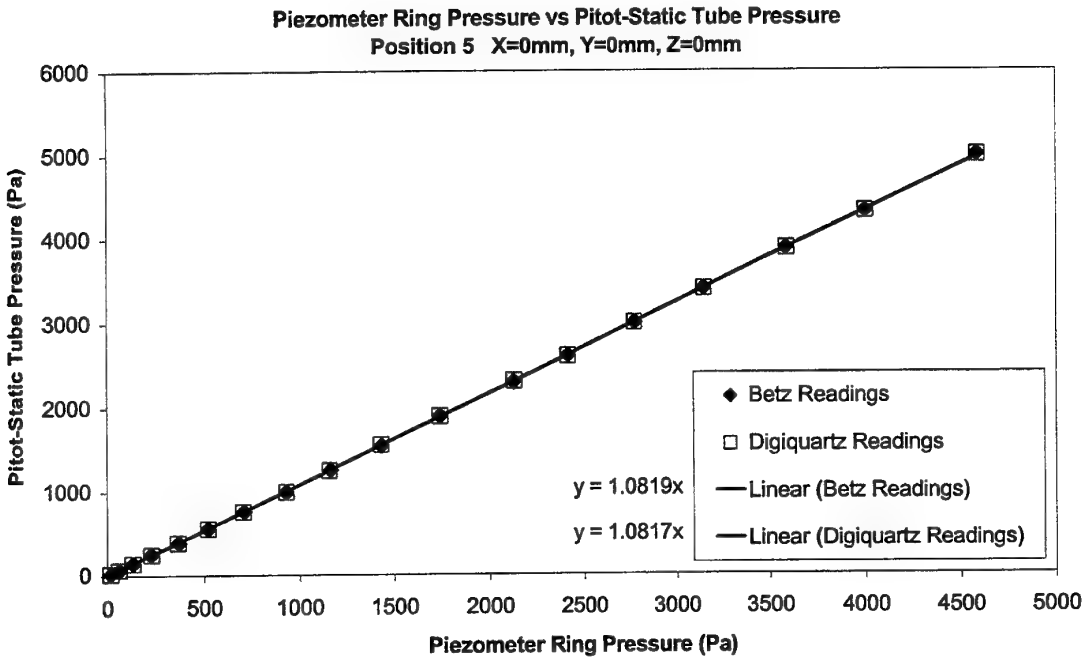


Figure 10. Linear regression of piezometer ring and pitot-static tube pressures - Position 5

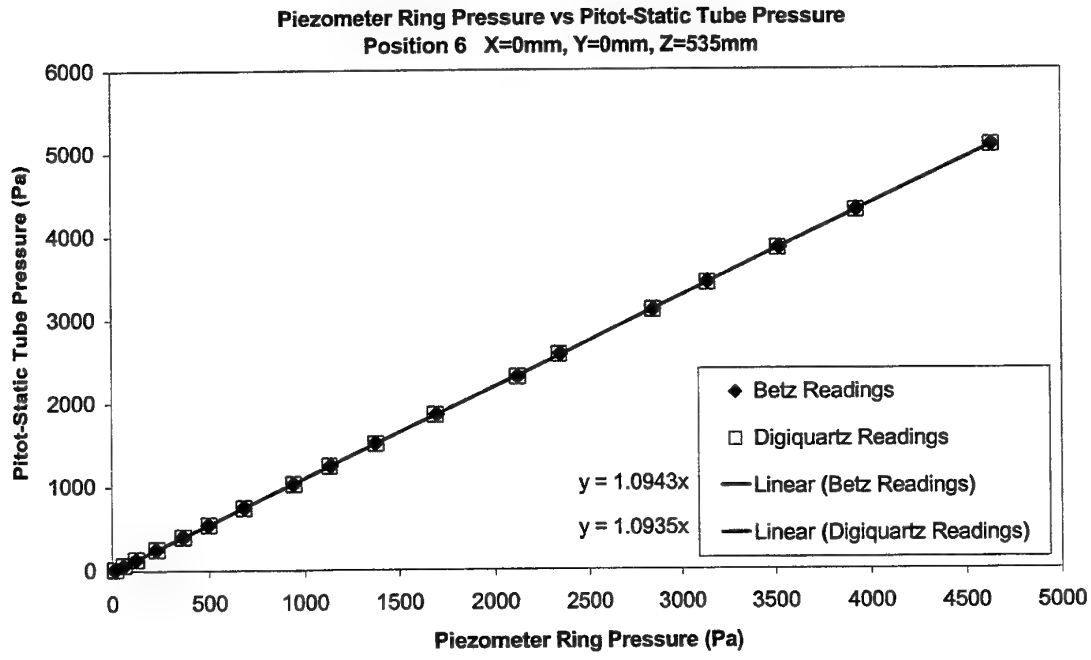


Figure 11. Linear regression of piezometer ring and pitot-static tube pressures - Position 6

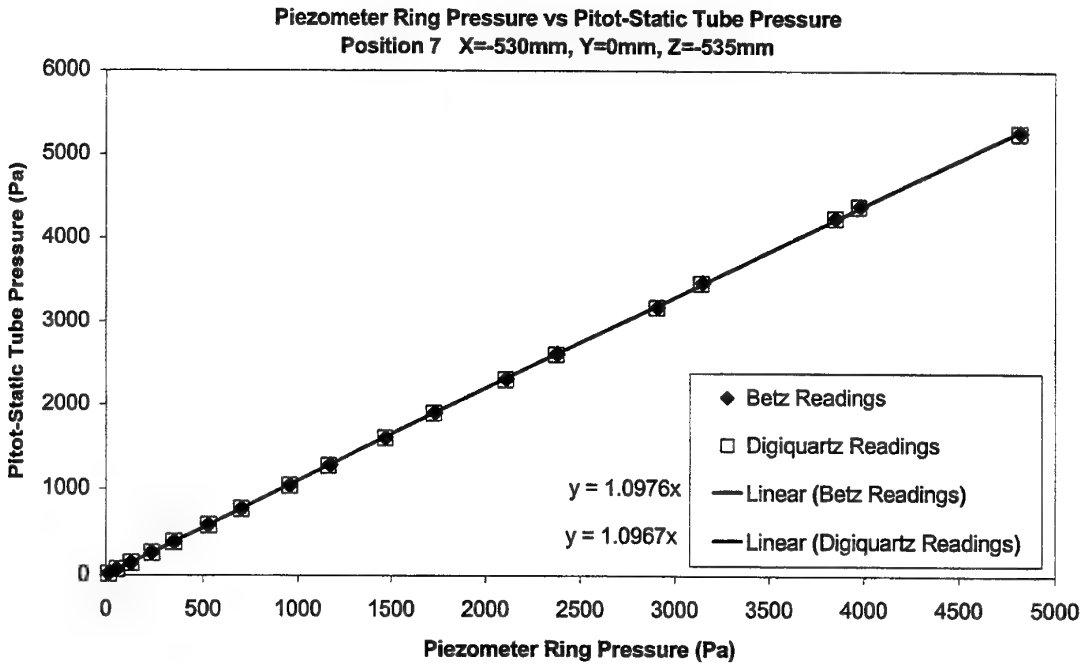


Figure 12. Linear regression of piezometer ring and pitot-static tube pressures - Position 7

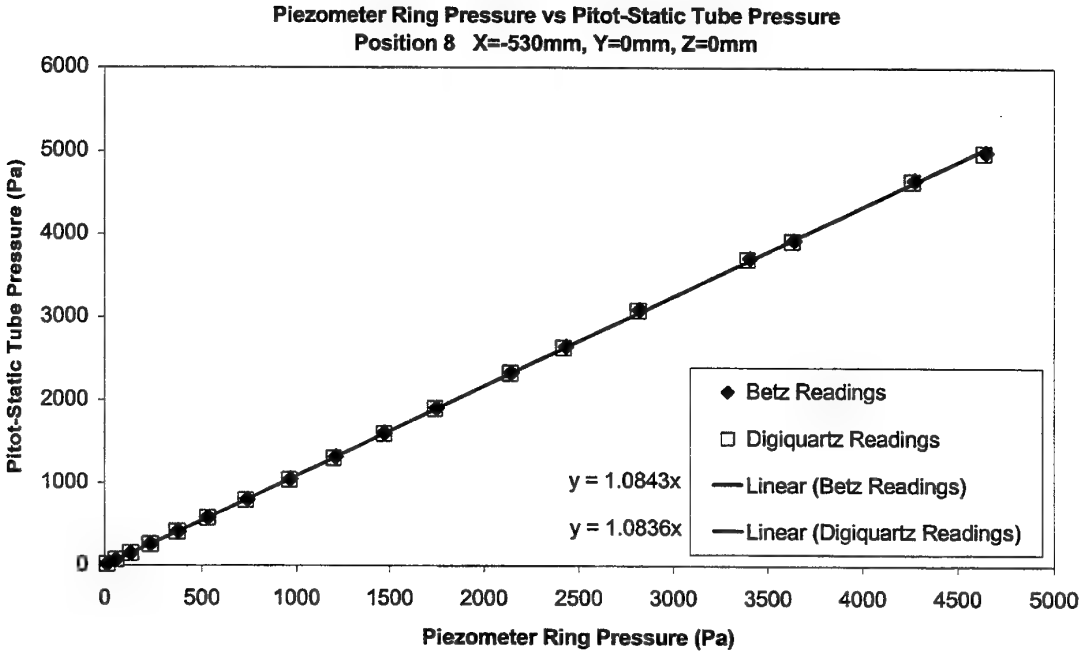


Figure 13. Linear regression of piezometer ring and pitot-static tube pressures - Position 8

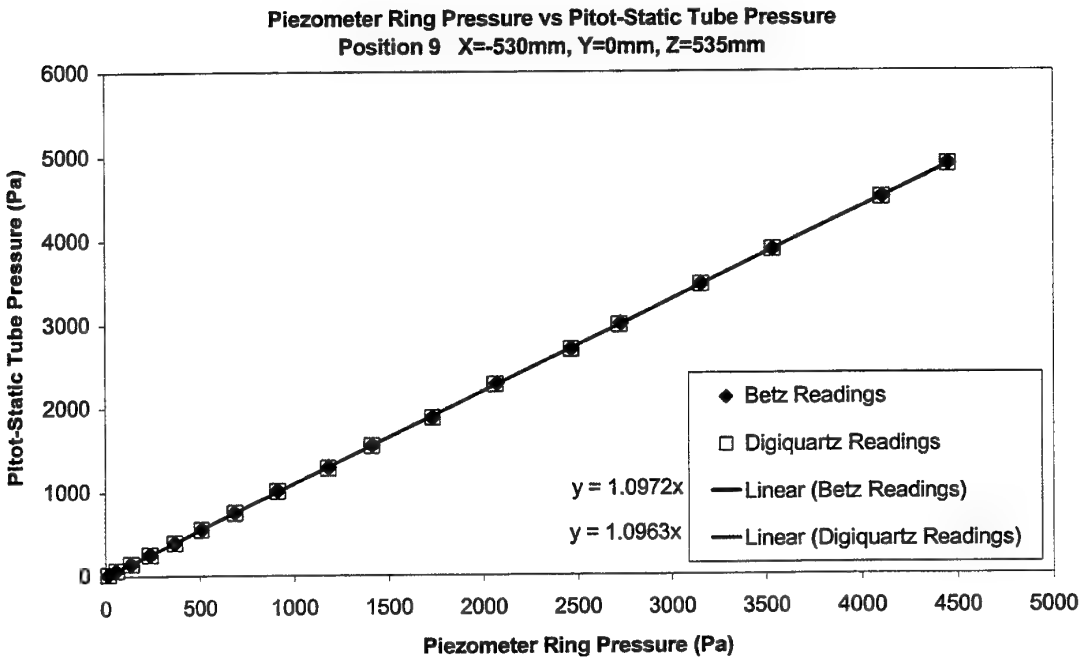


Figure 14. Linear regression of piezometer ring and pitot-static tube pressures - Position 9

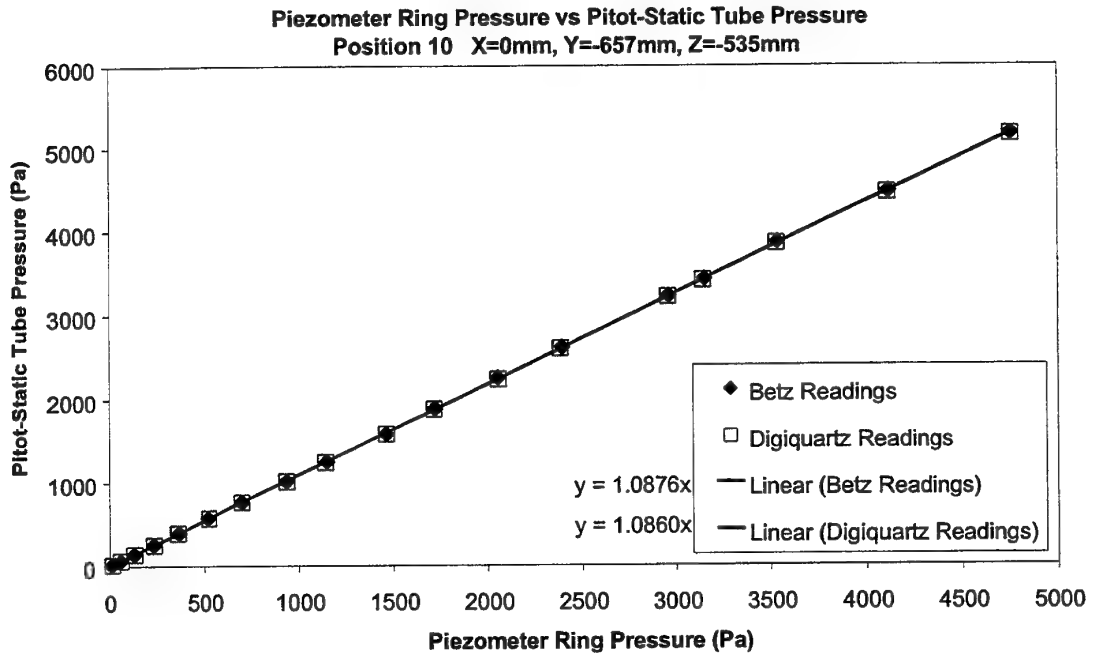


Figure 15. Linear regression of piezometer ring and pitot-static tube pressures - Position 10

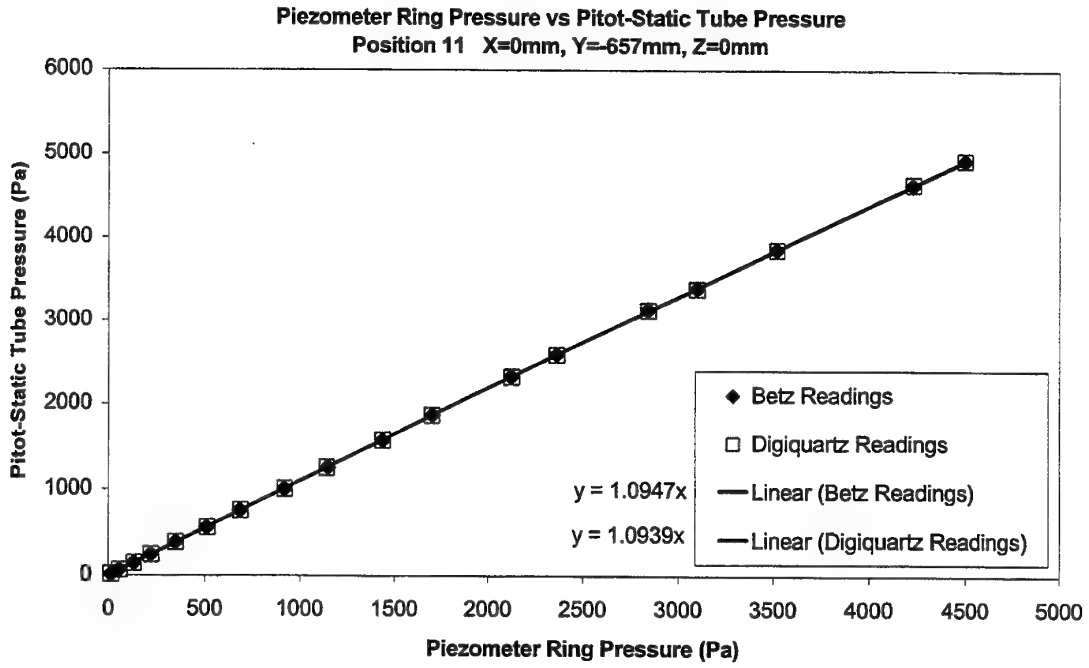


Figure 16. Linear regression of piezometer ring and pitot-static tube pressures - Position 11

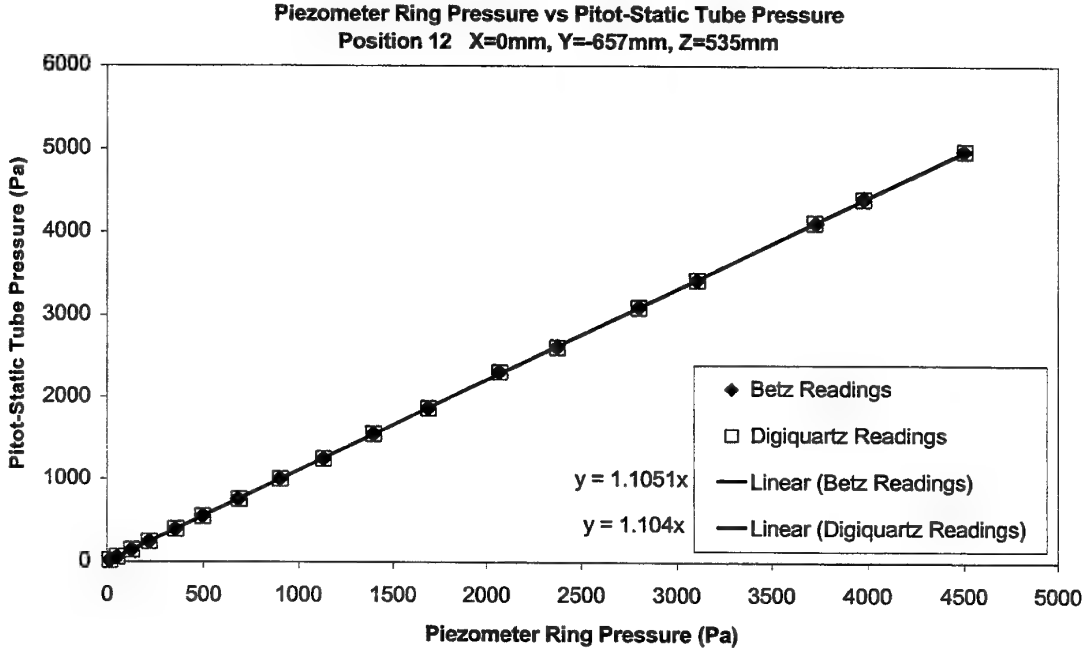


Figure 17. Linear regression of piezometer ring and pitot-static tube pressures - Position 12

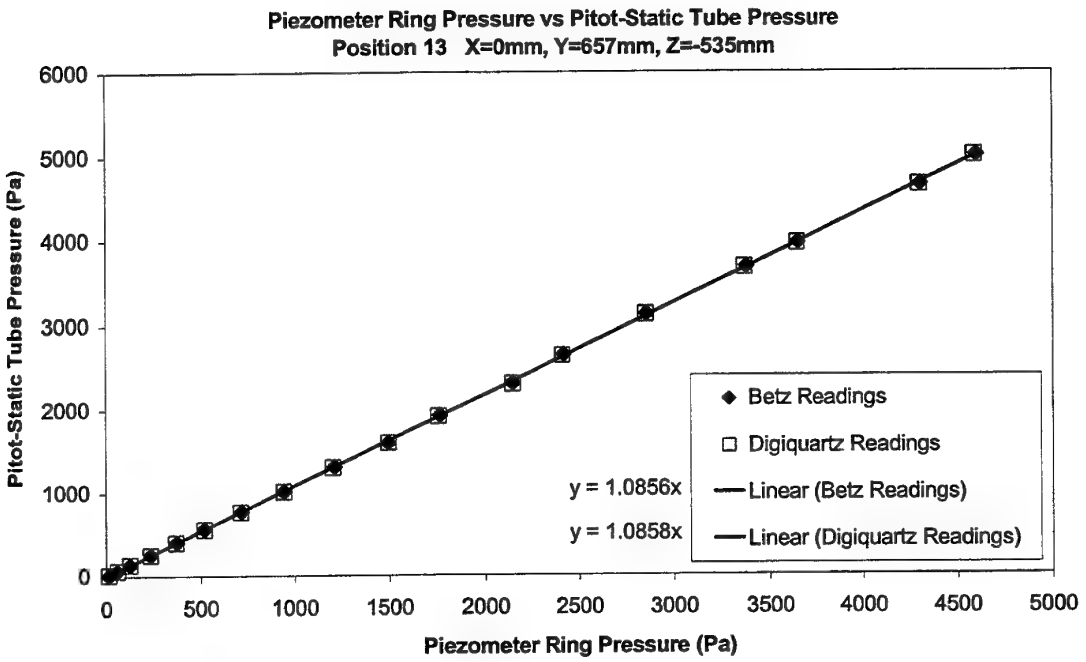


Figure 18. Linear regression of piezometer ring and pitot-static tube pressures - Position 13

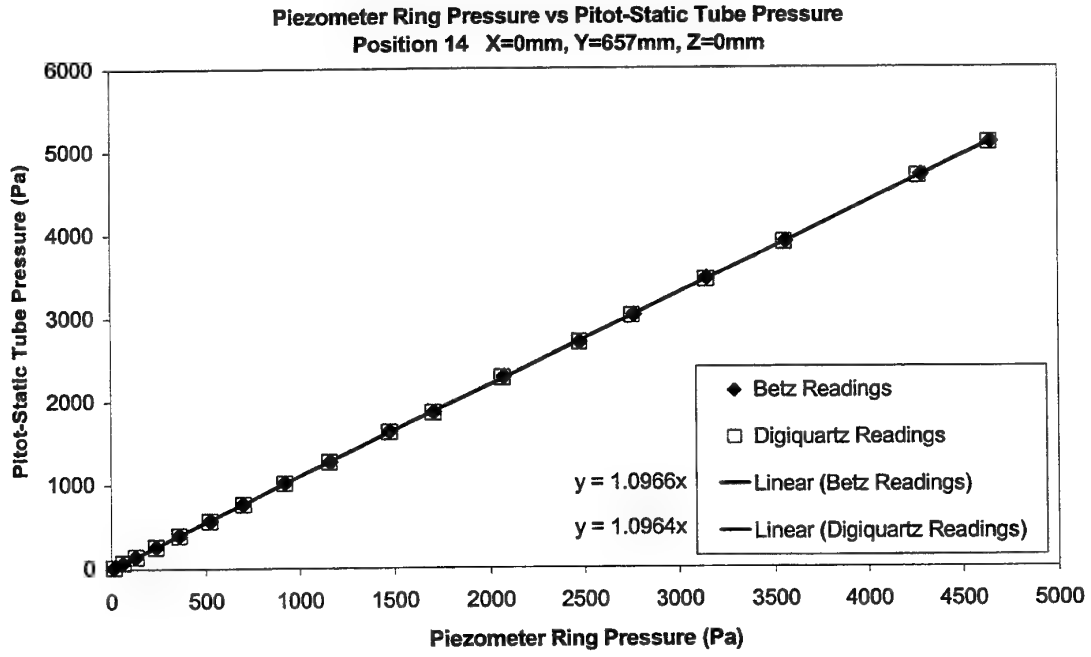


Figure 19. Linear regression of piezometer ring and pitot-static tube pressures - Position 14

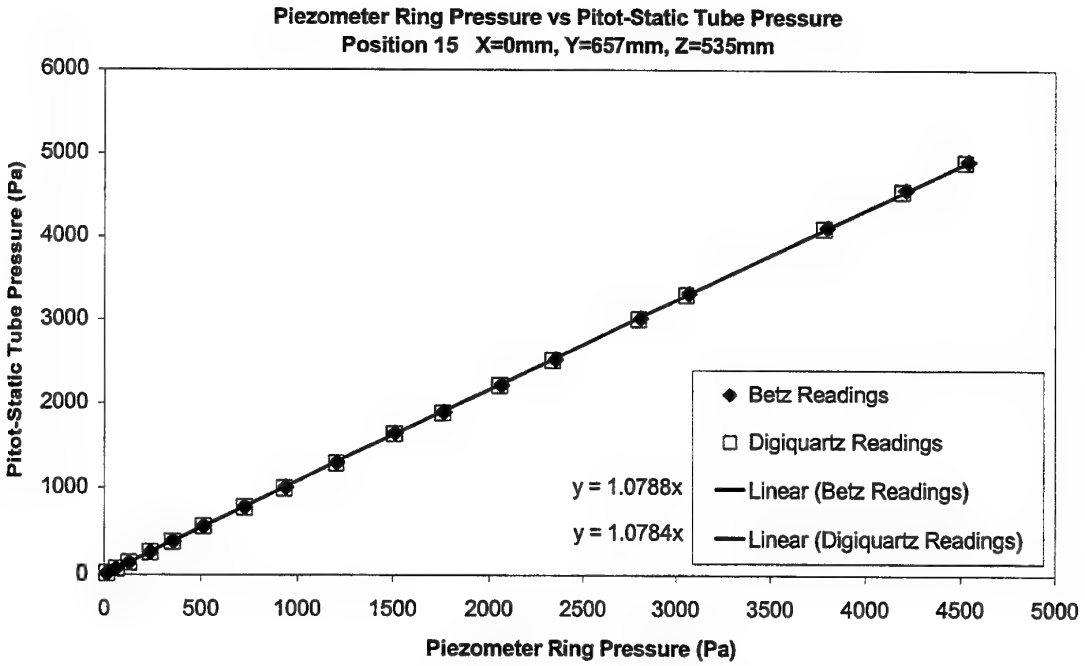


Figure 20. Linear regression of piezometer ring and pitot-static tube pressures - Position 15

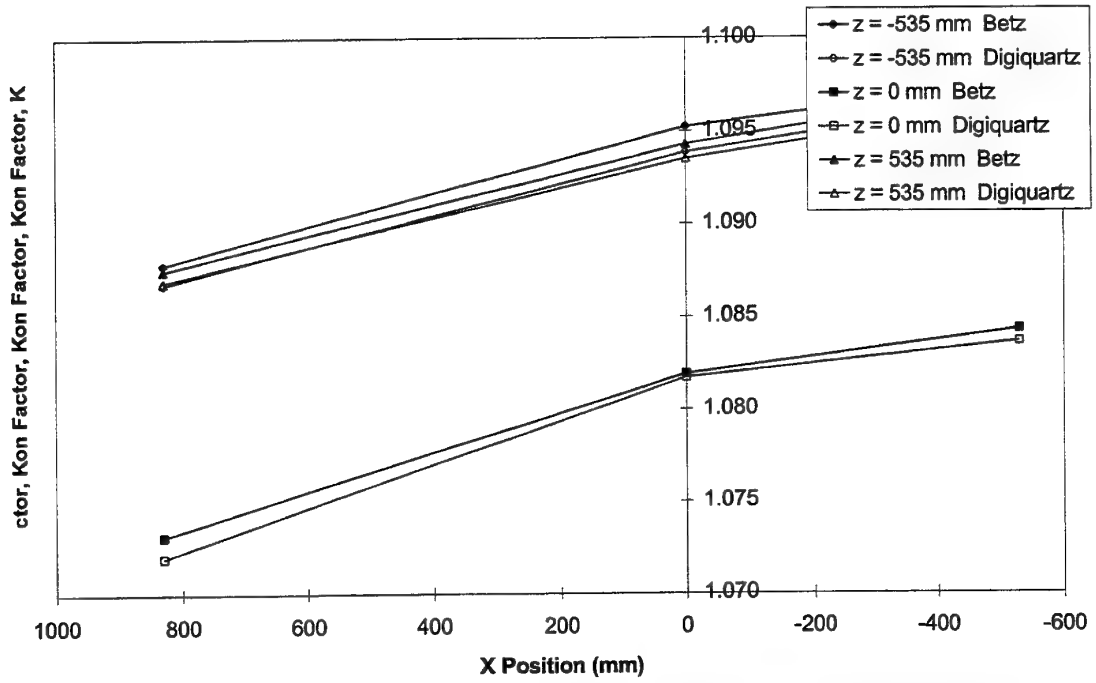


Figure 21. Variation of the wind tunnel velocity calibration factor in the vertical longitudinal plane of the test section through the centre of the turntables i.e. the XZ plane at Y=0 mm

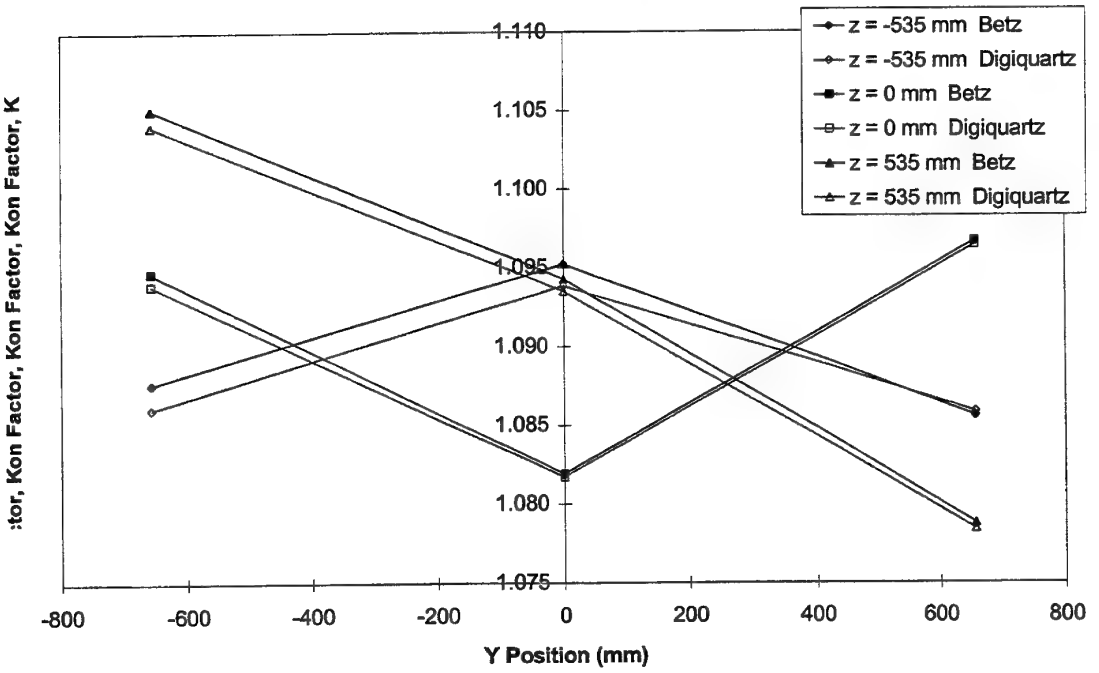


Figure 22. Variation of the wind tunnel velocity calibration factor across the test section at the centre of the turntables i.e. the YZ plane at X=0 mm

Appendix A: Tabulated Pressure Data

POSITION 1 - X = 830 mm, Y = 0 mm, Z = -535 mm
FILE: XPY0ZN.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.76	5.29	27.37	1.180	1.6	1.6	1.46	1.46	1.000	15.3	16.0	1.046
101.75	10.12	26.79	1.182	6.0	6.4	5.89	6.30	1.067	59.0	63.3	1.073
101.77	15.29	26.36	1.184	13.6	14.4	13.55	14.36	1.059	132.2	141.2	1.068
101.75	19.98	26.13	1.184	23.2	25.2	23.23	25.24	1.086	227.4	245.6	1.080
101.76	24.87	25.95	1.185	36.0	39.0	36.13	39.15	1.083	352.2	381.4	1.083
101.76	29.80	25.76	1.186	51.4	56.0	51.65	56.29	1.089	508.0	548.1	1.079
101.73	35.25	25.66	1.186	72.0	78.0	72.41	78.46	1.083	708.2	766.8	1.083
101.73	40.08	25.66	1.186	93.4	100.6	93.98	101.24	1.077	920.8	990.5	1.076
101.73	44.74	25.69	1.186	116.8	126.4	117.56	127.24	1.082	1143.0	1239.0	1.084
101.72	50.75	25.87	1.185	149.6	162.0	150.62	163.12	1.083	1474.9	1593.3	1.080
101.70	54.55	26.06	1.184	172.8	187.4	174.00	188.72	1.084	1697.4	1841.3	1.085
101.68	59.89	26.37	1.183	208.0	225.4	209.48	227.02	1.084	2053.2	2219.0	1.081
101.68	64.18	26.89	1.181	238.6	259.8	240.32	261.69	1.089	2350.5	2557.5	1.088
101.65	69.47	27.37	1.178	280.6	303.6	282.65	305.83	1.082	2768.5	2986.3	1.079
101.61	73.88	28.65	1.173	314.6	342.2	316.92	344.73	1.088	3103.0	3370.0	1.086
101.59	78.75	30.03	1.167	355.8	387.6	358.44	390.49	1.089	3508.3	3820.0	1.089
101.58	83.36	31.46	1.162	398.2	434.8	401.18	438.06	1.092	3927.4	4279.0	1.090
101.53	89.44	33.31	1.154	454.8	495.0	458.22	498.74	1.088	4484.5	4886.5	1.090

POSITION 2 - X = 830 mm, Y = 0 mm, Z = 0 mm
FILE: XPY0Z0.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.93	5.22	26.07	1.187	1.6	1.6	1.46	1.46	1.000	15.6	16.0	1.026
101.93	10.20	25.41	1.189	6.0	6.6	5.89	6.50	1.100	58.8	63.1	1.073
101.93	14.85	25.04	1.191	13.0	13.6	12.95	13.55	1.046	125.9	134.2	1.066
101.93	19.70	24.89	1.191	22.4	24.4	22.42	24.44	1.089	220.8	237.8	1.077
101.91	25.13	24.76	1.192	36.6	39.8	36.73	39.96	1.087	360.5	389.4	1.080
101.93	29.90	24.69	1.192	51.8	55.8	52.05	56.08	1.077	513.4	548.1	1.068
101.91	35.19	24.73	1.192	71.8	77.2	72.21	77.65	1.075	708.9	761.6	1.074
101.91	39.77	24.71	1.192	92.2	98.4	92.77	99.02	1.067	912.5	970.1	1.063
101.88	44.98	24.86	1.191	118.2	127.0	118.97	127.84	1.074	1160.1	1250.0	1.077
101.88	50.28	25.08	1.190	148.0	157.4	149.01	158.48	1.064	1463.5	1556.0	1.063
101.86	54.64	25.34	1.189	174.0	186.6	175.21	187.91	1.072	1712.7	1840.0	1.074
101.85	60.22	25.72	1.187	211.4	226.2	212.91	227.82	1.070	2091.0	2232.4	1.068
101.84	64.60	26.23	1.185	242.6	261.2	244.35	263.10	1.077	2390.9	2573.1	1.076
101.81	69.10	27.56	1.180	276.8	296.8	278.82	298.98	1.072	2726.2	2930.0	1.075
101.79	75.15	27.60	1.179	328.2	350.6	330.62	353.20	1.068	3245.9	3466.2	1.068
101.76	79.52	31.43	1.164	361.2	388.8	363.88	391.70	1.076	3573.6	3836.2	1.073
101.74	84.83	29.13	1.173	414.8	446.2	417.91	449.55	1.076	4101.5	4400.0	1.073
101.72	88.65	32.98	1.158	448.2	480.6	451.57	484.22	1.072	4432.4	4750.1	1.072

POSITION 3 - X = 830 mm, Y = 0 mm, Z = 535 mm
FILE: XPY0ZP.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
102.24	4.76	24.73	1.196	1.4	1.6	1.26	1.46	1.143	12.8	13.9	1.086
102.24	10.36	24.11	1.198	6.4	7.0	6.30	6.90	1.094	62.2	68.2	1.096
102.23	15.22	23.90	1.199	13.6	14.6	13.55	14.56	1.074	132.5	143.3	1.082
102.23	19.59	23.69	1.200	22.8	24.8	22.82	24.84	1.088	223.6	239.9	1.073
102.22	25.57	23.63	1.200	38.4	41.6	38.55	41.77	1.083	375.8	405.7	1.080
102.22	30.29	23.61	1.200	53.8	58.4	54.07	58.70	1.086	531.4	573.6	1.079
102.21	35.13	23.63	1.200	72.4	78.8	72.81	79.26	1.088	712.0	774.2	1.087
102.18	40.85	23.76	1.199	98.8	106.4	99.42	107.08	1.077	971.5	1046.7	1.077
102.18	44.32	23.94	1.198	115.8	126.0	116.56	126.84	1.088	1130.6	1232.2	1.090
102.16	49.35	24.05	1.198	143.0	155.6	143.97	156.67	1.088	1407.1	1527.5	1.086
102.14	55.58	24.51	1.195	180.8	197.0	182.07	198.39	1.090	1781.1	1936.4	1.087
102.13	58.71	25.14	1.193	202.6	219.6	204.04	221.17	1.084	1991.0	2156.5	1.083
102.09	66.69	26.42	1.187	259.0	282.0	260.88	284.06	1.089	2552.7	2774.7	1.087
102.08	69.10	27.12	1.184	280.4	302.2	282.45	304.42	1.078	2763.4	2972.2	1.076
102.01	77.38	34.31	1.156	340.2	370.4	342.72	373.16	1.089	3353.2	3653.1	1.089
102.01	79.41	33.74	1.158	359.8	391.4	362.47	394.32	1.088	3544.4	3856.0	1.088
101.96	86.16	35.05	1.153	422.2	459.6	425.36	463.06	1.089	4159.8	4525.0	1.088
101.96	91.07	36.88	1.146	469.4	511.4	472.93	515.27	1.089	4630.1	5044.4	1.089

POSITION 4 - X = 0 mm, Y = 0 mm, Z = -535 mm
FILE: X0Y0ZN.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.45	5.35	25.46	1.184	1.6	1.8	1.46	1.66	1.125	16.0	17.4	1.088
101.42	9.71	24.89	1.186	5.4	6.0	5.29	5.89	1.111	52.8	59.8	1.133
101.43	15.11	24.65	1.187	13.4	14.6	13.35	14.56	1.090	131.0	142.2	1.085
101.42	20.26	24.43	1.187	23.8	26.0	23.83	26.05	1.092	233.3	254.2	1.090
101.42	25.03	24.36	1.188	36.6	39.8	36.73	39.96	1.087	360.5	390.8	1.084
101.40	30.07	24.26	1.188	53.0	56.8	53.26	57.09	1.072	515.8	557.5	1.081
101.42	34.79	24.26	1.188	70.0	76.6	70.40	77.05	1.094	691.2	751.2	1.087
101.40	40.11	24.40	1.187	93.4	102.6	93.98	103.25	1.099	921.2	1006.5	1.093
101.38	44.60	24.41	1.187	115.8	126.4	116.56	127.24	1.092	1141.4	1238.5	1.085
101.39	50.02	24.64	1.186	144.8	159.0	145.78	160.09	1.098	1428.2	1565.3	1.096
101.36	55.02	24.90	1.185	175.6	191.6	176.83	192.95	1.091	1733.3	1885.2	1.088
101.36	59.34	25.39	1.183	204.4	224.0	205.85	225.61	1.096	2013.4	2204.4	1.095
101.34	64.89	25.70	1.181	243.8	266.0	245.56	267.94	1.091	2408.8	2622.4	1.089
101.31	68.86	27.06	1.176	273.6	298.8	275.60	300.99	1.092	2697.5	2942.3	1.091
101.28	76.19	28.39	1.170	333.4	365.8	335.87	368.52	1.097	3288.6	3600.0	1.095
101.28	77.74	33.04	1.152	341.6	374.4	344.13	377.19	1.096	3370.1	3693.2	1.096
101.25	83.99	34.20	1.148	398.2	436.6	401.18	439.88	1.096	3930.0	4310.0	1.097
101.20	91.84	36.01	1.140	475.2	520.6	478.78	524.54	1.096	4697.6	5140.0	1.094

POSITION 5 - X = 0 mm, Y = 0 mm, Z = 0 mm
FILE: X0Y0Z0.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.40	5.32	22.55	1.195	2.2	2.2	2.06	2.06	1.000	18.4	19.8	1.076
101.40	9.96	22.22	1.196	6.4	6.8	6.30	6.70	1.063	60.8	65.0	1.069
101.39	15.14	21.98	1.197	13.6	14.6	13.55	14.56	1.074	132.0	141.9	1.075
101.40	20.03	21.79	1.198	23.2	25.6	23.23	25.65	1.103	228.8	247.6	1.082
101.40	25.09	21.79	1.198	37.4	40.0	37.54	40.16	1.070	364.0	389.4	1.070
101.39	29.96	21.71	1.198	52.8	57.0	53.06	57.29	1.080	521.0	558.2	1.071
101.38	34.97	21.71	1.198	72.0	77.6	72.41	78.05	1.078	706.0	759.5	1.076
101.38	39.91	21.83	1.197	94.4	101.0	94.99	101.64	1.070	929.9	994.0	1.069
101.38	44.93	22.05	1.196	118.0	127.4	118.77	128.25	1.080	1157.0	1248.0	1.079
101.35	49.69	22.37	1.195	145.4	156.2	146.39	157.27	1.074	1433.4	1553.6	1.084
101.37	54.96	22.55	1.194	176.4	191.2	177.63	192.55	1.084	1741.4	1888.0	1.084
101.35	60.86	23.21	1.191	215.2	232.4	216.74	234.07	1.080	2127.1	2304.3	1.083
101.34	64.71	23.90	1.189	244.4	263.8	246.17	265.72	1.079	2411.9	2600.0	1.078
101.34	69.59	25.15	1.184	281.2	303.4	283.26	305.63	1.079	2775.0	2995.6	1.079
101.32	74.36	26.73	1.177	318.4	344.4	320.75	346.95	1.082	3147.1	3400.0	1.080
101.30	79.47	28.39	1.170	363.0	392.8	365.70	395.73	1.082	3588.8	3878.1	1.081
101.28	84.06	29.74	1.165	405.0	437.0	408.03	440.28	1.079	4000.9	4317.7	1.079
101.27	90.03	29.89	1.162	464.4	505.0	467.90	508.81	1.087	4587.6	4986.5	1.087

POSITION 6 - X = 0 mm, Y = 0 mm, Z = 535 mm
FILE: X0Y0ZP.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
102.12	5.21	29.02	1.177	1.6	1.8	1.46	1.66	1.125	16.3	17.4	1.067
102.13	10.08	28.36	1.180	6.0	6.2	5.89	6.09	1.033	60.8	65.3	1.074
102.12	14.70	27.58	1.183	12.6	13.6	12.54	13.55	1.079	124.5	135.6	1.089
102.12	20.04	27.34	1.184	23.2	25.6	23.23	25.65	1.103	230.0	251.7	1.094
102.11	25.32	27.32	1.184	37.2	40.8	37.34	40.97	1.097	365.4	400.0	1.095
102.12	29.56	27.19	1.185	50.4	55.2	50.64	55.48	1.095	499.5	543.2	1.087
102.10	34.60	27.12	1.185	69.4	75.6	69.79	76.04	1.089	683.2	743.6	1.088
102.08	40.59	27.14	1.184	95.4	104.0	95.99	104.66	1.090	943.7	1024.6	1.086
102.08	44.57	27.18	1.184	115.4	126.2	116.15	127.04	1.094	1132.3	1239.9	1.095
102.06	49.15	27.27	1.184	139.6	153.2	140.54	154.25	1.097	1379.0	1507.5	1.093
102.04	54.44	27.64	1.182	172.0	188.2	173.20	189.52	1.094	1690.0	1854.0	1.097
102.02	60.74	27.98	1.180	214.6	233.6	216.13	235.28	1.089	2119.2	2304.0	1.087
102.01	64.07	28.58	1.178	237.4	261.0	239.11	262.90	1.099	2338.0	2573.0	1.101
101.95	70.86	30.56	1.169	288.6	314.8	290.71	317.12	1.091	2847.5	3107.9	1.091
101.95	74.57	31.72	1.165	318.0	348.4	320.34	350.98	1.096	3139.9	3432.2	1.093
101.94	79.09	33.31	1.159	356.8	390.2	359.45	393.11	1.094	3518.0	3846.2	1.093
101.93	83.83	35.28	1.151	397.8	435.6	400.77	438.87	1.095	3927.4	4295.3	1.094
101.87	90.54	33.03	1.159	469.6	514.0	473.14	517.89	1.095	4638.0	5074.0	1.094

POSITION 7 - X = -530 mm, Y = 0 mm, Z = -535 mm
FILE: XNY0ZN.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.75	5.06	22.45	1.199	1.8	2.0	1.66	1.86	1.111	16.7	17.5	1.048
101.75	10.23	22.10	1.201	6.2	7.0	6.09	6.90	1.129	60.0	68.2	1.137
101.75	15.12	21.83	1.202	13.6	14.8	13.55	14.76	1.088	133.6	145.4	1.088
101.75	20.34	21.54	1.203	24.4	26.8	24.44	26.86	1.098	239.6	261.5	1.091
101.75	24.64	21.41	1.203	36.0	39.4	36.13	39.55	1.094	351.8	384.2	1.092
101.74	30.20	21.33	1.204	53.6	59.0	53.87	59.31	1.101	530.1	578.2	1.091
101.74	34.76	21.29	1.204	71.0	78.0	71.40	78.46	1.099	699.3	766.8	1.097
101.73	40.48	21.47	1.203	97.0	105.4	97.61	106.07	1.087	956.2	1038.7	1.086
101.73	44.80	21.47	1.203	118.8	129.8	119.58	130.67	1.093	1162.8	1273.0	1.095
101.72	50.25	21.73	1.202	149.2	162.4	150.22	163.52	1.088	1470.0	1600.0	1.088
101.71	54.63	22.01	1.201	175.8	192.8	177.03	194.16	1.097	1728.0	1895.0	1.097
101.70	60.20	22.32	1.199	213.8	233.4	215.33	235.08	1.092	2107.0	2297.0	1.090
101.67	64.02	23.08	1.196	241.0	264.2	242.74	266.12	1.096	2373.0	2598.0	1.095
101.64	70.70	23.57	1.193	294.4	321.4	296.56	323.77	1.092	2903.6	3169.0	1.091
101.61	73.79	24.43	1.190	318.8	351.6	321.15	354.21	1.103	3139.5	3459.0	1.102
101.55	81.86	25.58	1.184	389.8	429.6	392.71	432.82	1.102	3847.0	4239.0	1.102
101.56	83.46	28.55	1.173	403.2	444.4	406.21	447.74	1.102	3972.7	4378.9	1.102
101.51	92.00	30.85	1.163	488.0	534.0	491.68	538.04	1.094	4817.0	5262.3	1.092

POSITION 8 - X = -530 mm, Y = 0 mm, Z = 0 mm
FILE: XNY0Z0.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.74	4.90	16.41	1.224	1.6	1.8	1.46	1.66	1.125	14.9	17.0	1.141
101.75	10.07	16.09	1.226	6.4	7.0	6.30	6.90	1.094	62.6	67.8	1.083
101.73	15.11	16.01	1.226	14.2	15.2	14.16	15.16	1.070	137.3	147.8	1.076
101.74	20.26	15.96	1.226	24.4	26.6	24.44	26.65	1.090	237.8	257.0	1.081
101.73	25.17	16.07	1.225	38.8	42.0	38.95	42.17	1.082	374.8	406.0	1.083
101.72	30.01	16.03	1.225	54.2	59.0	54.47	59.31	1.089	532.0	574.5	1.080
101.72	35.19	16.23	1.225	75.2	81.2	75.64	81.68	1.080	731.7	790.0	1.080
101.70	40.28	16.39	1.224	98.2	105.8	98.82	106.48	1.077	962.8	1036.0	1.076
101.70	45.13	16.73	1.222	122.8	133.2	123.61	134.09	1.085	1199.9	1300.0	1.083
101.67	50.08	16.99	1.221	149.4	162.6	150.42	163.72	1.088	1472.0	1596.0	1.084
101.67	54.40	17.32	1.219	177.6	193.0	178.84	194.36	1.087	1743.4	1894.5	1.087
101.65	60.35	17.82	1.217	217.2	235.8	218.75	237.50	1.086	2139.5	2323.3	1.086
101.61	64.19	18.46	1.214	246.4	267.4	248.18	269.35	1.085	2419.5	2629.0	1.087
101.59	69.62	19.07	1.211	285.6	312.8	287.69	315.10	1.095	2813.6	3079.0	1.094
101.56	76.31	21.61	1.200	344.8	375.8	347.36	378.60	1.090	3391.3	3697.3	1.090
101.54	78.83	22.68	1.196	368.4	398.0	371.14	400.97	1.080	3628.9	3917.0	1.079
101.49	85.78	24.05	1.190	433.0	471.6	436.25	475.15	1.089	4264.7	4642.0	1.088
101.48	89.12	25.27	1.185	470.6	505.6	474.14	509.42	1.074	4639.0	4979.0	1.073

POSITION 9 - X = -530 mm, Y = 0 mm, Z = 535 mm
FILE: XNY0ZP.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.87	5.13	25.97	1.186	1.6	1.8	1.46	1.66	1.125	15.3	17.4	1.137
101.86	10.01	25.24	1.189	6.0	6.6	5.89	6.50	1.100	59.1	65.7	1.112
101.86	15.29	24.96	1.190	13.8	15.0	13.75	14.96	1.087	134.9	146.8	1.088
101.86	20.17	24.89	1.191	23.8	26.2	23.83	26.25	1.101	233.3	255.6	1.096
101.86	25.12	24.72	1.191	36.8	40.2	36.93	40.36	1.092	362.6	394.6	1.088
101.86	29.76	24.76	1.191	52.0	57.0	52.25	57.29	1.096	509.6	557.8	1.095
101.84	34.71	24.75	1.191	70.0	76.8	70.40	77.25	1.097	691.8	754.7	1.091
101.82	39.91	24.87	1.190	92.6	103.2	93.17	103.86	1.114	913.2	1009.6	1.106
101.82	45.26	24.97	1.190	119.8	131.0	120.59	131.87	1.093	1180.2	1284.5	1.088
101.80	49.65	25.15	1.189	143.4	157.2	144.37	158.28	1.096	1411.9	1545.5	1.095
101.80	54.72	25.62	1.187	175.4	190.4	176.62	191.74	1.086	1731.1	1880.2	1.086
101.79	60.05	26.07	1.185	209.8	231.0	211.29	232.66	1.101	2063.2	2272.2	1.101
101.77	65.47	26.50	1.183	249.8	273.4	251.61	275.39	1.094	2466.8	2692.3	1.091
101.75	68.96	26.96	1.181	276.4	303.6	278.42	305.83	1.098	2722.0	2987.3	1.097
101.72	74.28	28.45	1.175	319.8	351.4	322.16	354.01	1.099	3156.7	3466.3	1.098
101.67	84.79	29.53	1.170	415.8	456.2	418.91	459.63	1.097	4105.3	4498.8	1.096
101.72	78.96	31.35	1.164	358.2	392.4	360.86	395.33	1.095	3536.6	3878.8	1.097
101.64	88.90	33.12	1.156	451.0	495.4	454.39	499.14	1.098	4453.3	4887.9	1.098

POSITION 10 - X = 0 mm, Y = -657 mm, Z = -535 mm
FILE: X0YNZN.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.79	4.76	23.87	1.194	1.4	1.6	1.26	1.46	1.143	13.9	14.9	1.072
101.77	10.10	23.50	1.195	6.0	6.4	5.89	6.30	1.067	59.2	63.7	1.076
101.79	14.95	23.21	1.197	13.2	14.4	13.15	14.36	1.091	129.4	141.2	1.091
101.78	20.03	22.97	1.197	23.4	25.6	23.43	25.65	1.094	231.2	251.0	1.086
101.78	24.97	22.82	1.198	36.8	40.0	36.93	40.16	1.087	355.9	391.6	1.100
101.78	30.22	22.76	1.198	53.2	58.0	53.46	58.30	1.090	525.6	569.5	1.084
101.76	34.96	22.76	1.198	71.4	77.6	71.81	78.05	1.087	703.0	762.3	1.084
101.75	40.18	22.87	1.197	95.0	102.4	95.59	103.05	1.078	936.5	1007.5	1.076
101.73	44.51	22.94	1.197	116.6	126.2	117.36	127.04	1.082	1141.4	1238.4	1.085
101.73	50.29	23.19	1.196	148.6	160.0	149.61	161.10	1.077	1465.6	1578.0	1.077
101.72	54.57	23.53	1.194	174.4	190.4	175.62	191.74	1.092	1716.4	1876.0	1.093
101.70	59.83	23.89	1.193	208.0	227.6	209.48	229.23	1.094	2056.0	2234.0	1.087
101.68	64.43	24.52	1.190	242.6	264.4	244.35	266.32	1.090	2387.0	2600.0	1.089
101.65	71.72	25.22	1.187	300.0	326.4	302.20	328.81	1.088	2956.0	3216.3	1.088
101.63	74.01	25.93	1.184	319.0	346.8	321.35	349.37	1.087	3143.0	3411.1	1.085
101.59	78.74	28.11	1.175	358.2	391.0	360.86	393.92	1.092	3533.1	3850.0	1.090
101.56	85.07	29.57	1.169	416.8	452.8	419.92	456.20	1.086	4110.7	4457.5	1.084
101.53	91.44	30.59	1.165	481.6	522.8	485.23	526.75	1.086	4756.4	5157.4	1.084

POSITION 11 - X = 0 mm, Y = -657 mm, Z = 0 mm
FILE: X0YNZ0.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.91	5.31	29.87	1.172	1.6	1.6	1.46	1.46	1.000	15.6	16.3	1.045
101.90	10.02	29.26	1.174	6.0	6.4	5.89	6.30	1.067	59.5	63.3	1.064
101.91	15.44	28.77	1.176	13.6	14.8	13.55	14.76	1.088	134.2	145.0	1.080
101.89	19.83	28.52	1.177	22.6	24.6	22.62	24.64	1.088	223.6	242.7	1.085
101.90	24.89	28.30	1.178	35.6	39.2	35.72	39.35	1.101	350.4	384.5	1.097
101.90	30.14	28.17	1.178	52.0	56.8	52.25	57.09	1.092	515.5	559.9	1.086
101.89	34.92	28.11	1.178	69.8	76.4	70.19	76.85	1.095	690.1	756.0	1.095
101.87	40.19	28.11	1.178	93.2	101.4	93.78	102.04	1.088	921.9	1002.1	1.087
101.86	44.90	28.12	1.178	116.6	127.4	117.36	128.25	1.093	1144.5	1250.0	1.092
101.85	50.26	28.24	1.177	145.8	159.0	146.79	160.09	1.091	1440.6	1567.7	1.088
101.84	54.76	28.46	1.176	172.8	189.2	174.00	190.53	1.095	1702.2	1863.4	1.095
101.82	61.17	29.02	1.174	215.0	235.4	216.53	237.10	1.095	2126.4	2320.2	1.091
101.82	64.53	29.27	1.173	239.4	261.8	241.13	263.70	1.094	2365.4	2580.0	1.091
101.79	70.81	29.66	1.171	288.0	316.8	290.11	319.14	1.100	2844.4	3122.2	1.098
101.79	73.89	30.23	1.169	313.8	343.0	316.11	345.54	1.093	3099.9	3380.0	1.090
101.75	78.90	31.05	1.165	356.6	390.4	359.25	393.31	1.095	3523.3	3853.3	1.094
101.72	86.69	33.45	1.156	428.0	468.4	431.21	471.93	1.094	4230.0	4637.1	1.096
101.70	89.56	34.40	1.152	455.6	498.6	459.03	502.36	1.094	4500.2	4925.5	1.095

POSITION 12 - X = 0 mm, Y = -657 mm, Z = 535 mm
FILE: X0YNZP.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.86	4.87	29.90	1.171	1.6	1.8	1.46	1.66	1.125	15.3	17.7	1.157
101.84	9.49	29.38	1.173	5.6	5.8	5.49	5.69	1.036	53.9	57.1	1.059
101.86	15.02	29.10	1.174	13.0	14.4	12.95	14.36	1.108	128.3	142.2	1.108
101.85	19.66	28.86	1.175	22.4	24.8	22.42	24.84	1.107	220.5	243.8	1.106
101.86	25.11	28.65	1.176	36.0	39.8	36.13	39.96	1.106	357.5	392.5	1.098
101.85	29.66	28.51	1.176	50.6	55.8	50.84	56.08	1.103	498.1	547.8	1.100
101.85	34.84	28.42	1.177	69.4	76.4	69.79	76.85	1.101	689.1	754.7	1.095
101.84	39.98	28.46	1.176	91.6	101.6	92.16	102.24	1.109	905.9	998.9	1.103
101.83	44.69	28.46	1.176	115.0	126.4	115.75	127.24	1.099	1134.8	1245.0	1.097
101.81	49.65	28.62	1.175	141.6	157.0	142.56	158.08	1.109	1398.8	1548.3	1.107
101.81	54.55	28.79	1.175	171.2	188.8	172.39	190.13	1.103	1692.3	1861.1	1.100
101.79	60.39	29.17	1.173	209.4	233.6	210.89	235.28	1.116	2071.2	2304.2	1.112
101.77	64.61	29.57	1.171	240.4	264.6	242.13	266.52	1.101	2375.4	2606.2	1.097
101.75	70.35	30.20	1.169	283.8	313.6	285.88	315.91	1.105	2803.0	3094.1	1.104
101.73	74.11	31.23	1.164	314.4	346.6	316.72	349.17	1.102	3108.9	3424.4	1.101
101.71	81.27	31.93	1.161	377.8	416.6	380.61	419.72	1.103	3726.6	4117.2	1.105
101.68	84.08	33.03	1.157	403.0	446.0	406.01	449.35	1.107	3980.1	4400.0	1.105
101.67	89.66	34.93	1.150	455.6	503.8	459.03	507.61	1.106	4505.4	4977.5	1.105

POSITION 13 - X = 0 mm, Y = 657 mm, Z = -535 mm
FILE: X0YPZN.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.93	4.99	17.56	1.222	1.6	1.6	1.46	1.46	1.000	14.9	15.6	1.047
101.93	10.12	17.33	1.222	6.2	6.6	6.09	6.50	1.065	61.5	65.4	1.063
101.94	14.69	17.20	1.223	13.0	14.0	12.95	13.95	1.077	126.6	136.7	1.080
101.94	19.96	17.20	1.223	24.0	26.0	24.03	26.05	1.083	234.7	253.1	1.078
101.93	25.16	17.20	1.223	38.2	41.4	38.35	41.57	1.084	371.3	402.6	1.084
101.93	29.73	17.23	1.223	52.8	57.6	53.06	57.90	1.091	520.3	561.1	1.078
101.91	34.81	17.37	1.222	72.6	78.6	73.02	79.06	1.083	711.3	769.4	1.082
101.90	39.93	17.55	1.221	95.8	103.0	96.40	103.65	1.075	943.4	1013.2	1.074
101.89	45.25	17.86	1.220	122.8	132.8	123.61	133.69	1.081	1202.0	1303.7	1.085
101.87	50.17	18.20	1.218	151.8	162.0	152.84	163.12	1.067	1497.7	1598.8	1.068
101.86	54.76	18.69	1.216	179.0	194.8	180.25	196.18	1.088	1758.6	1916.0	1.090
101.85	60.15	19.11	1.214	217.2	233.6	218.75	235.28	1.076	2144.4	2297.0	1.071
101.82	64.15	19.63	1.212	245.0	267.8	246.77	269.75	1.093	2411.2	2632.2	1.092
101.79	70.04	20.17	1.209	289.0	316.2	291.12	318.53	1.094	2851.6	3119.3	1.094
101.76	76.04	22.12	1.201	342.0	372.6	344.53	375.37	1.089	3368.3	3671.1	1.090
101.75	79.20	23.16	1.196	369.6	401.2	372.35	404.20	1.085	3646.5	3957.2	1.085
101.71	86.13	25.59	1.186	435.8	471.0	439.07	474.55	1.081	4300.0	4648.2	1.081
101.68	89.30	26.80	1.181	465.8	506.2	469.31	510.02	1.087	4591.0	5000.0	1.089

POSITION 14 - X = 0 mm, Y = 657 mm, Z = 0 mm
FILE: X0YPZ0.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
101.94	5.03	23.16	1.199	1.6	1.8	1.46	1.66	1.125	15.6	17.4	1.115
101.94	10.49	22.94	1.199	6.4	7.2	6.30	7.10	1.125	63.3	70.2	1.109
101.94	14.93	22.68	1.200	13.2	14.4	13.15	14.36	1.091	130.0	141.5	1.088
101.94	20.21	22.51	1.201	24.2	26.4	24.24	26.45	1.091	236.1	257.0	1.089
101.93	25.00	22.37	1.202	36.8	40.4	36.93	40.56	1.098	361.9	393.9	1.088
101.93	29.99	22.40	1.202	53.4	57.6	53.66	57.90	1.079	521.4	564.1	1.082
101.92	34.71	22.34	1.202	70.8	77.4	71.20	77.85	1.093	699.1	760.0	1.087
101.91	39.91	22.44	1.201	93.6	103.4	94.18	104.06	1.105	921.5	1011.1	1.097
101.90	44.73	22.63	1.200	117.8	129.0	118.57	129.86	1.095	1157.6	1266.7	1.094
101.87	50.54	22.83	1.199	149.8	165.4	150.82	166.55	1.104	1476.6	1624.3	1.100
101.87	54.13	23.01	1.198	173.0	188.8	174.20	190.13	1.091	1704.7	1856.5	1.089
101.86	59.76	23.41	1.197	209.8	231.4	211.29	233.06	1.103	2063.3	2277.7	1.104
101.85	65.37	24.08	1.194	251.0	273.4	252.82	275.39	1.089	2476.1	2700.0	1.090
101.83	69.09	24.71	1.191	279.8	306.4	281.84	308.65	1.095	2752.3	3016.6	1.096
101.80	73.96	26.02	1.185	318.6	350.4	320.95	353.00	1.100	3143.3	3443.3	1.095
101.77	78.87	28.08	1.177	360.4	395.4	363.08	398.35	1.097	3551.2	3895.2	1.097
101.74	86.68	30.30	1.168	433.8	475.8	437.06	479.39	1.097	4269.5	4689.9	1.098
101.70	90.49	31.55	1.163	470.8	516.0	474.35	519.90	1.096	4643.8	5091.1	1.096

POSITION 15 - X = 0 mm, Y = 657 mm, Z = 535 mm
FILE: X0YPZP.DAT

Freestream Parameters				Betz Manometer					Digiquartz		
P (kPa)	V (ms^{-1})	T (°C)	ρ (kgm^{-3})	Measured ΔP_{piezo} (mmH_2O)	Measured ΔP_{pitot} (mmH_2O)	Corrected ΔP_{piezo} (mmH_2O)	Corrected ΔP_{pitot} (mmH_2O)	K	ΔP_{piezo} (Pa)	ΔP_{pitot} (Pa)	K
102.28	5.25	17.21	1.227	1.8	1.8	1.66	1.66	1.000	15.6	17.1	1.096
102.27	10.48	17.11	1.227	6.6	7.2	6.50	7.10	1.091	66.5	70.6	1.062
102.27	14.92	16.86	1.229	13.4	14.2	13.35	14.16	1.060	130.4	139.5	1.070
102.27	20.24	16.83	1.229	24.6	26.2	24.64	26.25	1.065	241.4	257.7	1.068
102.27	24.60	16.83	1.229	36.6	39.0	36.73	39.15	1.066	357.1	380.3	1.065
102.27	29.56	16.94	1.228	52.6	57.0	52.86	57.29	1.084	515.1	558.5	1.084
102.26	35.08	16.97	1.228	73.8	79.0	74.22	79.47	1.070	725.9	775.1	1.068
102.25	39.76	17.27	1.227	95.4	102.2	95.99	102.85	1.071	933.0	997.2	1.069
102.24	45.17	17.84	1.224	123.0	131.4	123.81	132.28	1.068	1208.2	1285.5	1.064
102.23	50.66	18.22	1.222	153.4	166.4	154.45	167.55	1.085	1510.6	1632.1	1.080
102.20	54.69	18.59	1.220	179.0	191.6	180.25	192.95	1.070	1762.1	1880.2	1.067
102.19	59.20	20.07	1.214	209.2	224.4	210.69	226.01	1.073	2055.5	2209.9	1.075
102.17	63.47	23.12	1.201	238.2	255.6	239.92	257.45	1.073	2336.0	2510.1	1.075
102.15	69.43	23.72	1.199	285.0	305.8	287.09	308.05	1.073	2802.6	3004.5	1.072
102.14	73.08	27.85	1.182	310.8	335.8	313.09	338.28	1.080	3055.8	3297.5	1.079
102.08	80.89	25.28	1.192	385.0	416.2	387.87	419.32	1.081	3786.3	4093.7	1.081
102.07	85.64	28.93	1.177	426.8	462.0	430.00	465.48	1.082	4196.5	4542.2	1.082
102.05	89.07	30.24	1.172	460.0	496.8	463.46	500.55	1.080	4530.1	4893.2	1.080

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Craig D. Edwards

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low speed wind tunnel, pressure measurement, calibration, velocity measurement, piezometers, dynamic pressure

19. ABSTRACT

The measurement of wind velocity in the test section of the Low Speed Wind Tunnel is obtained from the measurement of dynamic pressure using two piezometer rings located at the entrance and exit of the tunnel contraction. Following the recent installation of a new contraction, a calibration of the dynamic pressure measurement system was performed to determine a new wind tunnel 'calibration' factor. This factor is applied as a correction to the pressure measurements obtained from the two piezometer rings to represent accurately the correct dynamic pressure and consequently, velocity, at the centre of the test section midway between the centres of the turntables in the floor and ceiling. A sub-standard pitot-static probe was used to acquire pressure data at various positions within the wind tunnel test section for a range of velocities. The new tunnel calibration factor, representative of all wind speeds, was determined to be 1.079, an increase of 3.3% over the factor of 1.045 for the previous contraction. This report contains all of the test data and a detailed account of the procedure and equipment used to derive this new calibration factor.